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ABSTRACT

This text is designed to provide teachers, students, and the general public with an overview of key solar energy concepts. Various energy terms are defined and explained. Basic thermodynamic laws are discussed. Alternative energy production is described in the context of the present energy situation. Described are the principal contemporary solar applications, including passive solar, mass walls, windows as solar collectors, attached greenhouses, and solar water heating. The document is designed to be used with a companion volume of teacher notes. (Author/RE)

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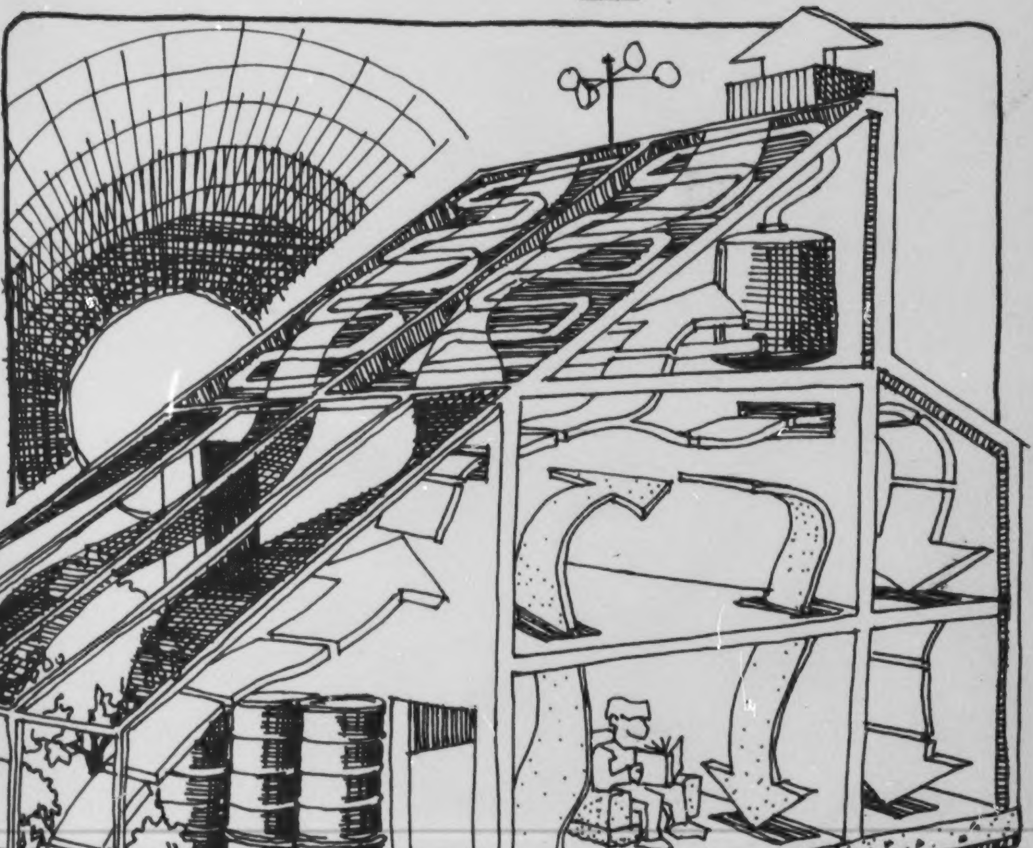

a background text

SE 027 601

Solar Concepts:
a background text

by

Jonathan W. Gorham

for

Maine Audubon Society

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DEDICATION

This curriculum is dedicated both to Jack Urbanski, the former Construction Trades Department Chairman at Portland Regional Vocational Technical Center (PRVTC), and to the students in the solar program. We appreciate the patience and constant candid comments of these 11th and 12th grade students. They offered us an invaluable learning laboratory for the first teaching of these materials. May this curriculum help them become the first true generation of solar technicians.

The assistance of numerous other people deserves mention. Steve Gagnon co-taught the course and designed and documented four of the student projects. C. Michael Lewis illustrated the text. Linda Suttenfield worked on the original Maine Audubon materials and prepared the slide show. Charlie Wing and Rick Karg of Cornerstones provided technical critiques of the text. Tim Garrison York typed the final draft. Many consultants added specific bits and pieces, but special help came from Rick Schwolsky of Vermont Design Group, Conrad Heeschen of Sunsystems, Robert S. Gorham, Jr., of Solar Design Associates, John Crowley of MIT, Cathey Murray of the Maine State Office of Energy Resources, and David Cox, a former Cornerstones student.

Thanks also go to the Homesworth Corporation of Brunswick for supplying the window insulating shutter instructions.

Responsibility for the conception, implementation and writing of these materials belongs to me. Any and all feedback from solar educators would be welcomed. I consider this curriculum to be like a crude 16th century chart of the oceans. In future years, it will appear pathetically inadequate, but if it heads us in the right direction, then it will have served a valuable function.

Jonathan W. Gorham

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March 1, 1979

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CHAPTER ONE

ENERGY LINGO

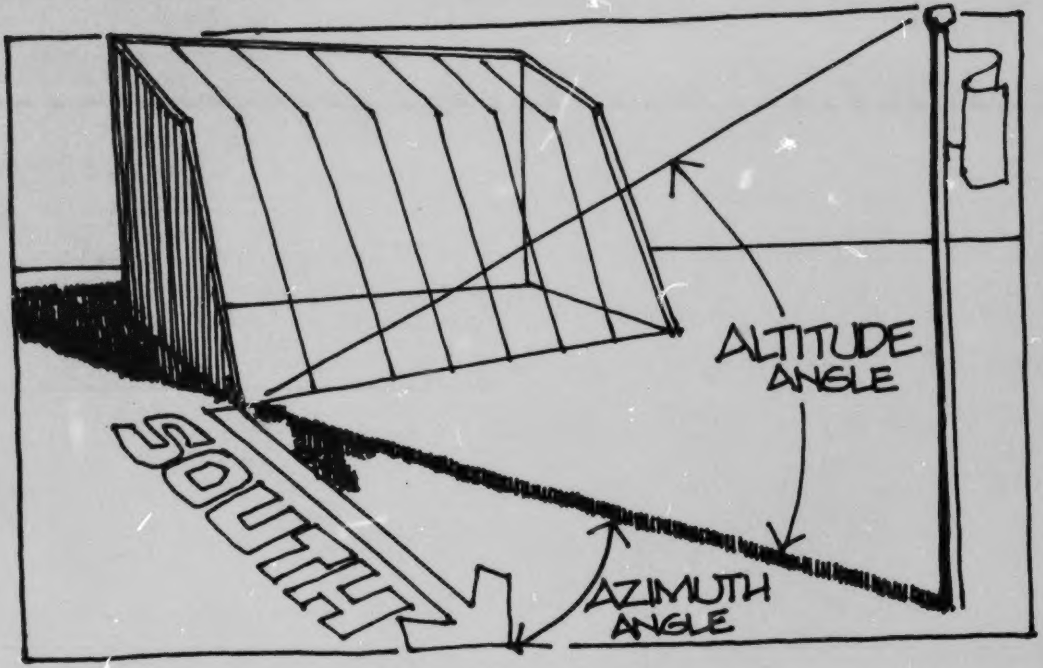
Every discipline has its own language. To the plumber, carpenter and electrician, the words "grout", "dado", and "conduit" all have a precise meaning. To ordinary homeowners these words are probably meaningless.

The field of solar energy also has its own terminology. There exists a core vocabulary of energy terms which must be understood in order to make sense out of this fast-growing field. Many of these words have been borrowed from other disciplines. Some of the words belong principally to solar. Collectively, these terms form a core solar vocabulary.

SOLAR TERMS

Active system: a space or hot water heating system that requires continuous inputs of non-renewable energy to move the collected heat. The use of electrical fans or pumps makes a solar system "active".

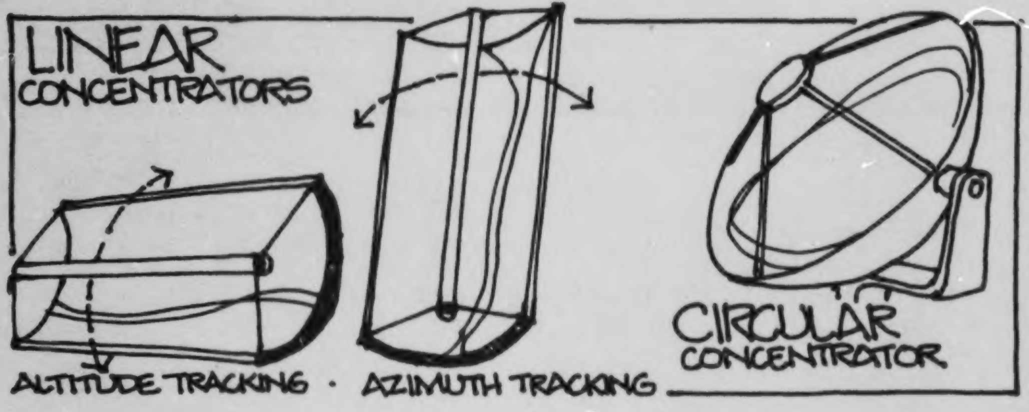
Altitude angle: the angle formed by an object overhead and the horizon. In Portland, Maine, the maximum altitude angle of the sun is 69°, occurring at noon on June 21.



Azimuth angle: the angle formed by the projection of a line to an object onto a horizontal plane and by a true north/south line. The azimuth angle is designated by three bits of information: a) the direction the surveyor points initially, either north or south; b) the number of degrees turned; and c) the direction turned, either south or west. Example: a solar array facing 45° west of south has the azimuth angle of S45°W.

BTU: British Thermal Unit. The amount of heat required to raise the temperature of one pound of water one Fahrenheit degree. Example: suppose a TV football fan removes a 16 fluid oz. bottle of beer from the refrigerator but leaves it on the kitchen table. After two hours the 16 fluid oz. (approximately one pound of water) has warmed up from 48°F. (its temperature in the refrigerator) to 68°F. (room temperature). In so doing, 20 BTU have been added to the bottle. (1 lb. x 20F.° = 20 BTU).

Concentrator: a device using reflectorized surfaces which focuses the sun's rays on one point or one line. Solar concentrators are used to achieve high temperatures.



Conduction: the transfer of heat due to the interaction of neighboring molecules. The handle of a frying pan gets warm by the conduction of heat through the molecules of the metal pan.

Convection: the transfer of heat by a moving fluid, usually air or water. The heat transfer fluid in a solar collector convects heat from the absorber plate to the heat exchanger.

Degree-days: a unit which describes the severeness of a particular climate. The number of degree-days for a particular day equals (65°F. - average outdoor temperature). For example, if the low temperature for Dec. 18 was 22°F. and the high for the day was 36°F., the number of degree-days for that day equals

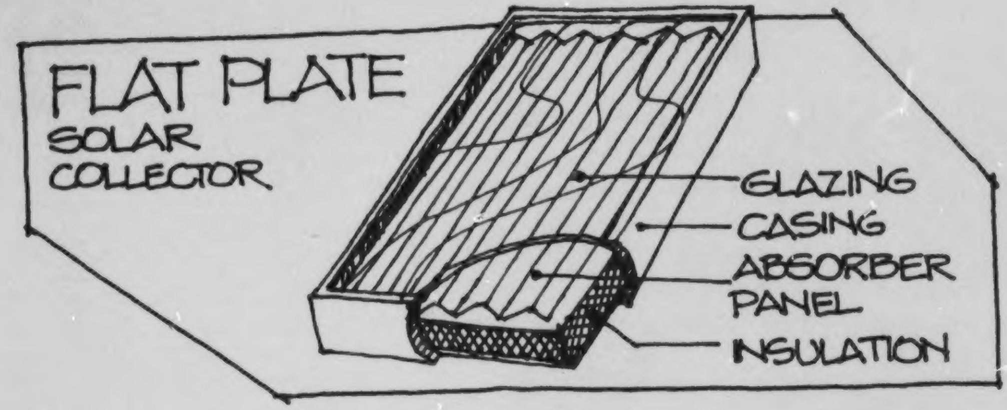
$$(65^\circ\text{F.} - \frac{36+22^\circ\text{F.}}{2}) = (65^\circ\text{F.} - 29^\circ\text{F.}) = 36 \text{ degree-days.}$$

Portland, Maine accumulates about 7500 degree-days per heating season; Caribou, Maine about 10,000.

Energy: the application of a force through a distance, or the ability to cause change. Energy exists in a variety of forms, e.g. electrical, kinetic (motion), gravitational, light, atomic, chemical, heat.

Entropy: a measure of the disorder of a system. A garden left unattended exhibits greater entropy (disorder) than a cultivated garden. The second law of thermodynamics states that the amount of entropy in the universe is constantly increasing. Example: the amount of concentrated, easily available fossil fuel energy is decreasing rapidly. Sometimes it requires more energy to mine certain veins of coal than the energy we obtain from that harvested coal.

Flat plate collector: a flat, rectangular box which is used to collect energy from the sun's rays. The principal components of a flat plate collector are: glazing, absorber panel, insulation, and casing.



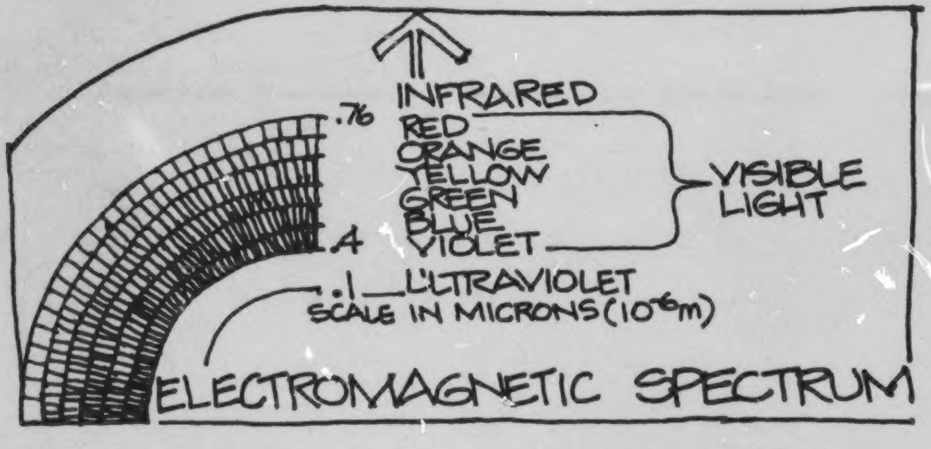
Glazing: the transparent or translucent cover of a solar collector, or that material which forms a window or skylight. In solar applications, glass or fiberglass is usually used as a glazing.

Heat: the total amount of thermal energy a body possesses. In solar collection we strive to transform solar (light) energy into heat energy to be collected.

Hydronic: a solar system which uses a liquid as its transfer medium. This fluid is usually water or a solution of water and anti-freeze.

Infiltration: the unwanted exchange of cold outside air with warm inside air. Leaks around windows and doors are a major source of infiltration heat loss.

Infrared: that part of the electromagnetic spectrum below ("infra") the red band of visible light. Infrared or long wave radiation is also called heat radiation. Fifty-one per cent of all radiation coming from the sun is infrared. All forms of electromagnetic radiation tend to degrade to heat.



Insolation; sunlight striking the earth. Insolation comes from the words incident solar radiation. The weather department now keeps insolation data, or sunshine statistics.

Insulation: any material that is used to slow the transfer of heat. Homes are generally insulated with fiberglass, cellulose, or ureaformaldehyde foam.

Joule: the primary energy term in the Metric System (S.I.) 1 Joule = a kilogram mass accelerated at a rate of 1 meter/sec^2 through the distance one meter.

$$1 \text{ Joule} = 1 \text{ kg } \frac{m^2}{sec^2}$$

There are about 1 million Joules of chemical energy stored in a jelly donut. In one BTU there are a little over 1000 Joules.

Kilocalorie: a measure of thermal energy equaling 1000 calories. A kilocalorie is the amount of heat required to raise one cubic decimeter, or one liter, or one kilogram of water one Celsius degree. 4 BTU = 1 kilocalorie.

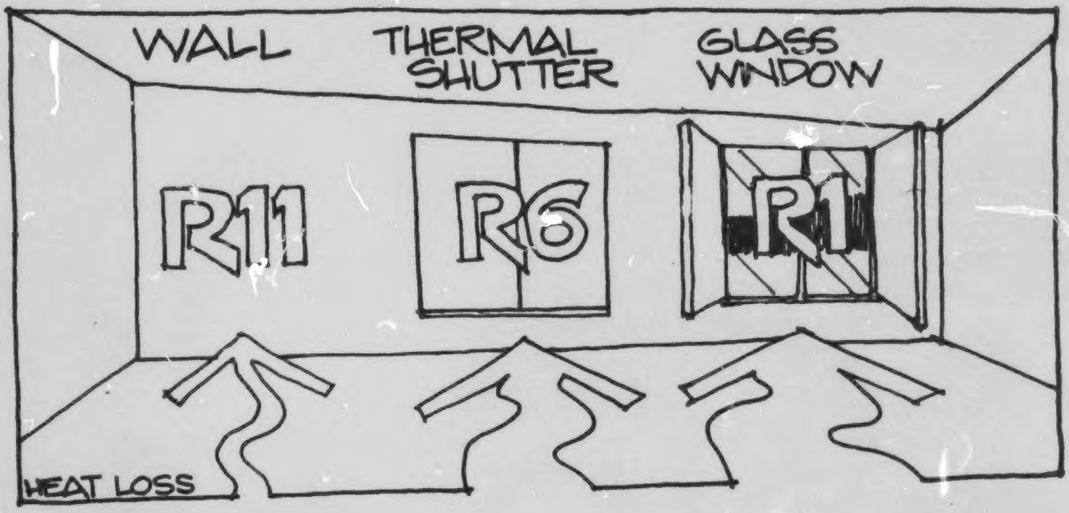
Passive system: a solar system which primarily relies on renewable energy sources for collecting, storing and distributing heat. A thermosyphon hot water collector which relies on natural convection (not a pump) to propel the water is an example of a passive system.

Photovoltaic: the process by which sunlight is converted directly into electricity. Photovoltaic cells are often made of chemically doped silicon which encourages the movement of electrons stimulated by sunlight.

Power: energy used per unit time. The power rating of a particular light bulb, say a 100-watt bulb, is that rate at which the bulb consumes energy. A large fossil fuel power plant has a rating of about one thousand million watts, or 1000 MW.

Quad: an energy term equal to one quadrillion BTU, or 10^{15} BTU. In 1973 the U.S. used 73 quads. A quad should be differentiated from a Q, or quintillion BTU (10^{18} BTU).

R-value: a measure of the relative ability of a material to resist or retard heat transfer. 3½ inches of fiberglass insulation has an R-value of 11. A good thermal window shutter has an R-value of 6. A single pane window has an R-value of 1.



Radiation: the method by which heat is transferred through open space. About 60% of the heat transferred to a room from a wood stove is by radiation. Sunlight travels to us by radiation through the void of space.

Retrofit: the thermal upgrading of a structure. Major retrofit options available to homeowners include: weather stripping, insulating shutters, storm windows, extra insulation, a solar greenhouse, etc.

Specific heat: the amount of heat needed to raise the temperature of one pound of a substance one Fahrenheit degree. The specific heat of water is 1.0, whereas the specific heat of masonry is around 0.2. Therefore it takes about 5 times more heat to raise the temperature of an equal weight of water than masonry.

Temperature: a measure of the energy of motion of the atoms and molecules of a substance. We use thermometers and thermistors to measure an object's temperature. The tip of a burning match has a high temperature, but the object as a whole might contain very little heat due to its size.

Therm: a unit used in heating calculations equal to 100,000 BTU. A gallon of #2 fuel oil when burned in an average oil furnace gives off about one therm. 100 cubic feet of natural gas also gives off about 1 therm.

Thermodynamics: the study of heat flow and dynamics. James P. Joule formulated some of the principal laws of thermodynamics in the mid-19th century.

Thermal mass: mass used to store heat energy -- usually collected solar energy. Both rock bins and containers filled with water have been used successfully as thermal masses.

Ultraviolet: a part of the electromagnetic spectrum beyond ("ultra") the violet band of visible light. About 4% of the solar energy reaching the surface of the earth is ultraviolet (UV). Ultraviolet radiation causes sun tans.

Watt: a unit of power equal to one Joule per second. An average sized human being continuously radiates thermal energy at the rate of about 100 Watts.

JUXTAPOSING KEY TERMS

The following pairs of energy terms are contrasted for further explanation.

1. Energy vs. Power

Energy is defined as the ability to cause change, or the application of a force through a distance. Energy takes many forms. One form is kinetic energy, or the energy of motion. Kinetic energy can be calculated by the formula $KE = \frac{1}{2}mv^2$. Remember the definition of a Joule:

$$1 \text{ Joule} = 1 \text{ kg} \frac{m^2}{sec^2}$$

Consider the following example:

How much kinetic energy does a car of mass (m) 1500 kg have when it is traveling at a speed of 20 meters/second?

$$KE = \frac{1}{2}mv^2$$

$$KE = \frac{1}{2}(1500 \text{ kg})\left(\frac{20m}{sec}\right)^2$$

$$KE = \frac{1}{2}(1500 \text{ kg}) \frac{400m^2}{sec^2}$$

$$KE = 300{,}000 \text{ kg}\frac{m^2}{sec^2}$$

$$KE = 300{,}000 \text{ Joules}$$

$$KE = 3 \times 10^5 \text{ Joules}$$

Since all forms of energy ultimately degrade to heat, we can calculate the maximum number of BTU this car could generate if 100% conversion occurred. When the driver steps on the brakes, some of this kinetic energy is instantly converted to heat within the brake drums and linings

1054 Joules = 1 BTU, or about 10^3 Joules

$$\frac{300{,}000 \text{ Joules}}{1000 \text{ Joules/BTU}} = 300 \text{ BTU}$$

The amount of heat that builds up is about equal to 300 BTU.

ENERGY QUANTITIES IN BTU

10^{21} = solar energy incident on the world in one year

10^{20} = energy available from proven reserves of world's fossil fuels

10^{19} = solar energy striking the surface of the U.S. in one year

10^{17} = energy consumed in one year in the United States

10^{15} = mQ (milli-Quint) or 10^{12} BTU

10^{8} = solar energy striking the roof of an average American house in one year

10^{6} = chemical energy content of one barrel of oil

10^{4} = chemical energy in one pound of butter

10^{3} = chemical energy in one jelly donut

10^{2} = kinetic energy of a car traveling at 20 m/second

10^{1} = chemical energy in a flashlight battery

10^{0} = 1 BTU

10^{-3} = one Joule

POWER

Power is the rate at which energy is expended. The Watt (W) is the standard metric system unit of power. The Watt is defined as one Joule/second, or

$$\text{Watt} = \frac{\text{kg}\cdot\text{m}^2}{\text{sec}^2}\ \frac{1}{\text{sec}} \quad \text{or} = \frac{\text{kg}\cdot\text{m}^2}{\text{sec}^3}$$

A kilowatt (kW) is defined as 1000 Watts or 1000 Joules/second.

If we assume that the engine in the above case produced constant power while accelerating from 0 to 20 m/sec, that it required 10 seconds to reach 20 m/sec, and that no losses were incurred due to friction, then we can calculate the power of the engine:

$$\text{power} = \frac{\Delta \text{ energy}}{\Delta \text{ time}}$$

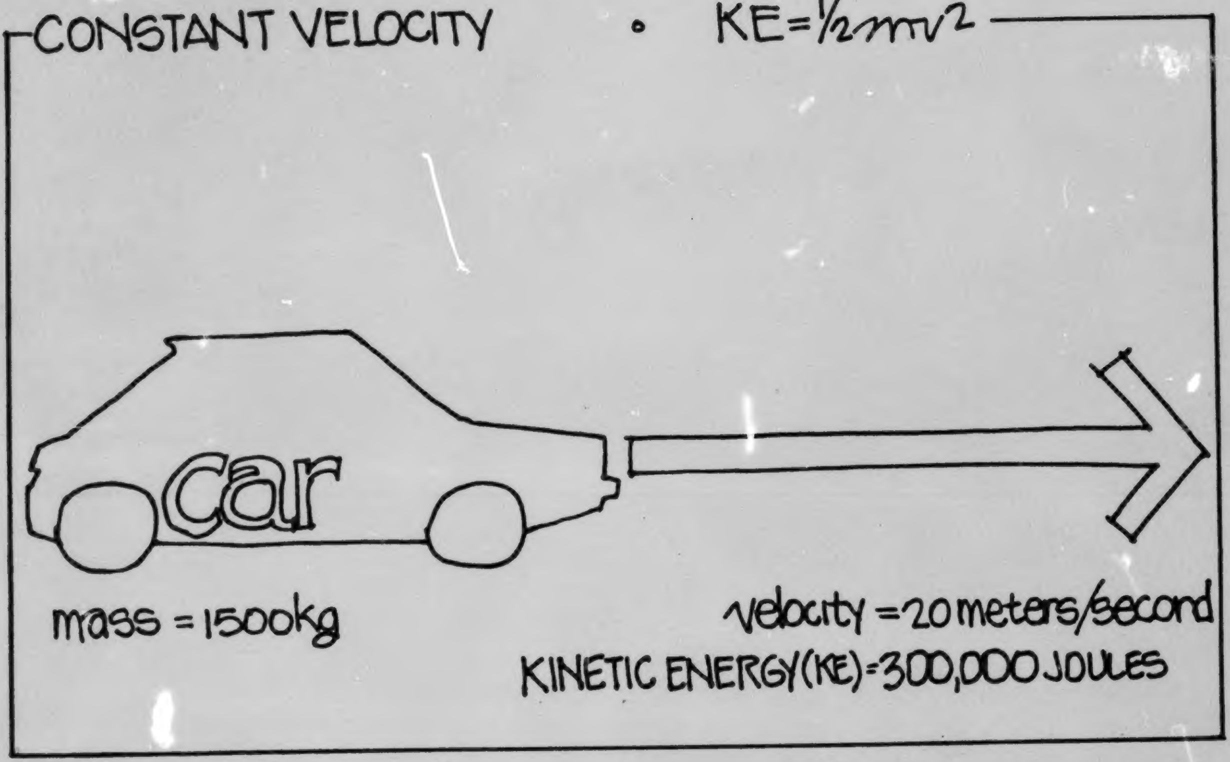
$$= \frac{3 \times 10^5 \text{Joules}}{10 \text{ seconds}}$$

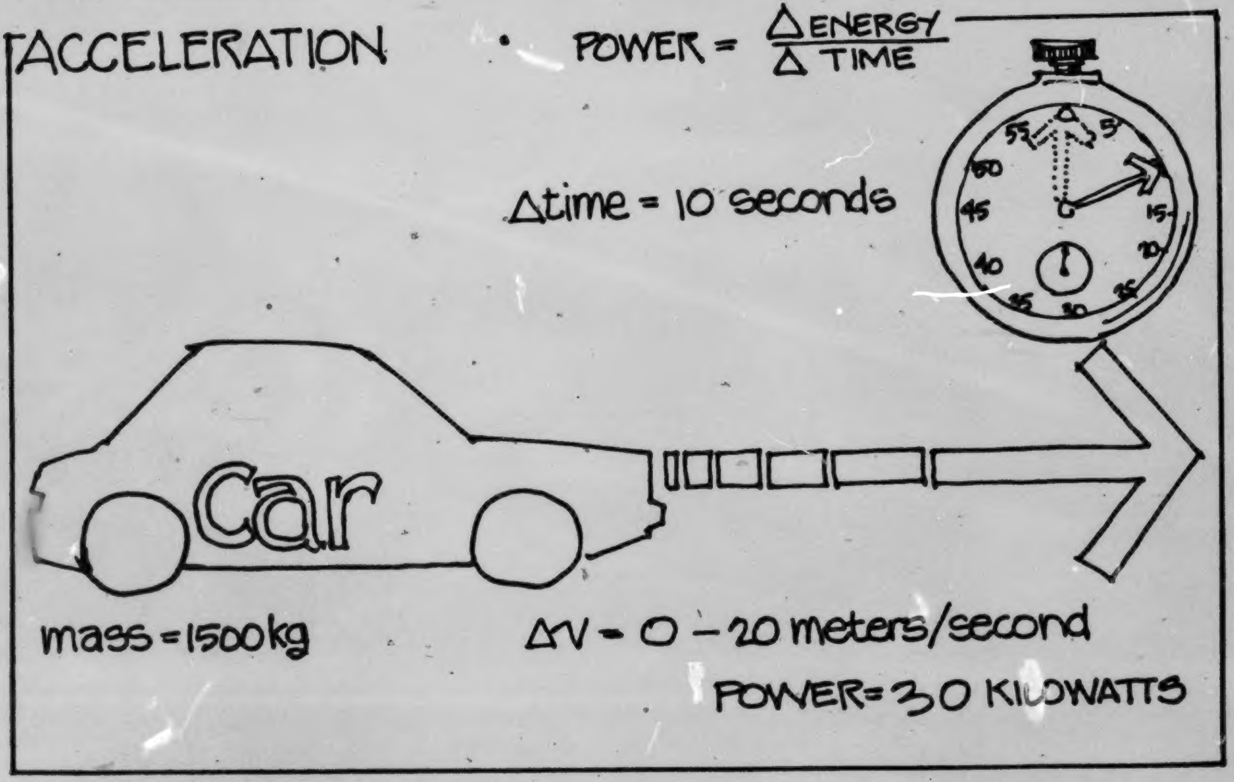
$$= 3 \times 10^4 \ \frac{\text{Joule}}{\text{sec}}$$

$$= 3 \times 10^4 \text{ Watt}$$

$$= 30 \text{ kiloWatts}$$

Because energy can be transformed from one form to another, we can use the Joule as the unit of kinetic, potential, heat and chemical energies.


CONSTANT VELOCITY
• KE=½mv²
Car
mass = 1500kg
velocity = 20 meters/second
KINETIC ENERGY (KE) = 300,000 JOULES


ACCELERATION
• POWER = Δ ENERGY / Δ TIME
Δtime = 10 seconds
55
5
50
45
15
40
20
35
30
25
Car
mass = 1500kg
ΔV = 0 – 20 meters/second
POWER = 30 KILOWATTS

HEAT ENERGY

The calorie was developed to describe thermal conditions. One calorie (c) is defined as the amount of heat required to raise one gram of water one Celsius degree. Dieticians use the unit Calorie (with a capital C), which equals 1000 calories. Therefore the Calorie, the unit commonly used in dietary studies, equals one kilocalorie. Like its English equivalent, the BTU, the calorie is anachronistic because heat energy can be expressed in Joules, and its use over a period of time in Watts. Nevertheless, the popularity of the terms BTU and calorie continues.

(Energy) $1 \text{ Joule} = 1 \text{ kg } \frac{m^2}{sec^2}$

(Power) $1 \text{ Watt} = 1 \text{ kg } \frac{m^2}{sec^3}$

(Thermal capacity) 1 calorie = 4.184 Joules

BTU

In the English system, the most common unit is BTU, or

British Thermal Unit. One BTU equals the amount of heat required to raise one pound of water one Fahrenheit degree.

Three other energy terms are:

Q (Quintillion) = 10^{18} BTU

Quad = 10^{15} BTU = mQ

langley = 1 cal/cm^2 or 3.69 BTU/ft^2

(Energy) 1 Joule = 1 Watt-second
= .000278 Watt-hour
= .000948 BTU
= .239 cal

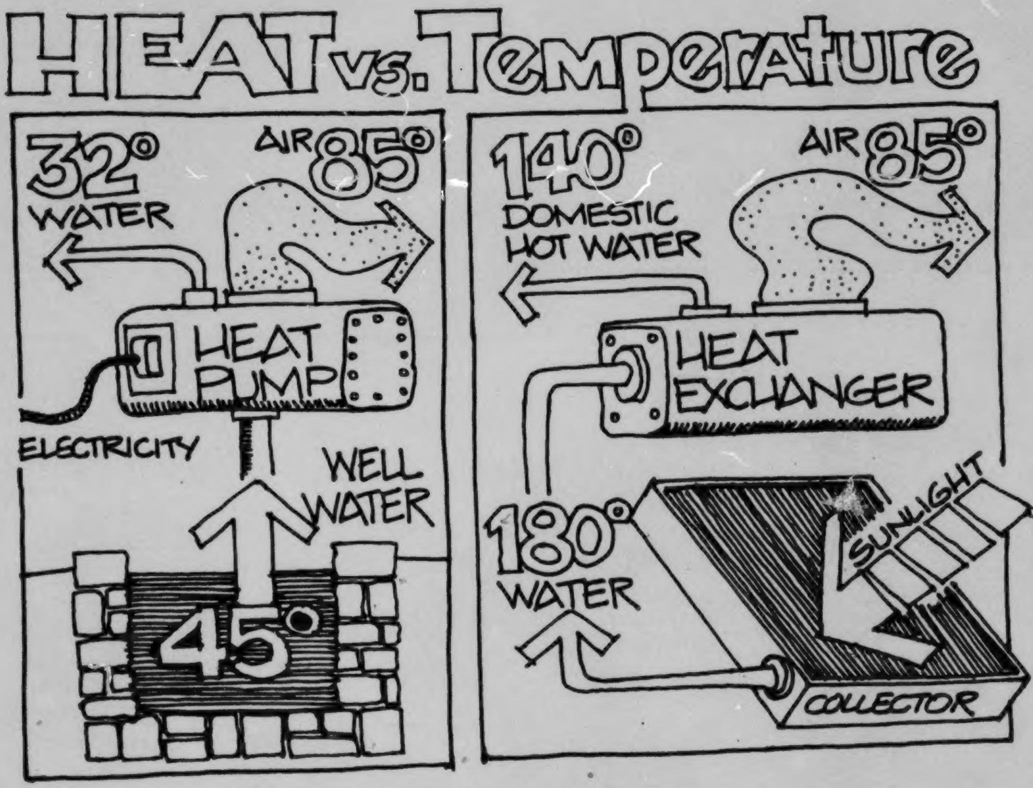
(Power) 1 Watt = 1 Joule/sec
= 3.414 BTU/hr
= 14.34 cal/min

2. Heat vs. Temperature

All too often the words "heat" and "temperature" are used synonymously. Thermodynamically, the concepts are quite different. Temperature is a measure of the amount of thermal energy a substance possesses. Thermal energy is an internal energy; that is, it relates to the amount of disorderly kinetic energy that exists on a microscopic level. The greater the excitation of the individual molecules, the higher the temperature of that substance will be.

Take, for example, two teapots of water placed on electric stove burners of exactly equal size. One teapot is filled with 500 ml. of water, the other with 1000 ml. (1 liter). If each burner is turned to high heat for an equal amount of time (6 minutes), an equal amount of electrical energy is transformed to heat on each burner. After 6 minutes, the temperature of the water in each teapot can be measured. Obviously, the teapot containing less water will be of higher temperature. The energy transfer, or heat flow, was exactly equal, yet the water temperatures in the two pots differ.

This distinction between heat and temperature is made apparent in the operation of certain heat pump systems. These units can extract useful heat from sources of relatively low temperature. For example, there is a house in Rhode Island that gets all its heating, cooling and hot water from the thermal energy extracted from well water of about 45°F. Its water seems too low in temperature to be of any great use, but because of the investment of electrical energy in the heat pump, the thermal energy of the water can be extracted.


HEAT vs. Temperature
32° WATER
AIR 85°
HEAT PUMP
ELECTRICITY
WELL WATER
45°
140° DOMESTIC HOT WATER
AIR 85°
HEAT EXCHANGER
180° WATER
SUNLIGHT
COLLECTOR

3. Ultraviolet vs. Infrared Radiation

The second law of thermodynamics states that the amount of disorder in the universe is increasing. Consistent with this law, high quality (low entropy) energy forms like electricity and light tend to degrade to thermal energy of low quality (high entropy).

The longer the wavelength of the light, the lower the energy level. Ultra means beyond; infra means below. Visible light broken down into its component colors gives us a method of understanding these terms. Remember: when there is light, there can also be heat. Useful solar radiation can be collected even on a cloudy day. A light bulb gets very hot when it is aglow. In fact roughly 95% of the electrical energy flowing through a light bulb is converted directly into thermal energy; only 5% is given off as visible radiation. All energy tends to degrade to thermal energy.

4. Active, Passive and Hybrid Solar Systems

There exists much debate in the solar energy field over the distinctions among active, passive and hybrid systems. Some people feel the engineers and architects are splitting hairs. However, understanding these distinctions is extremely important, because some solar energy systems require so much non-renewable energy to work that their net energy gain is low.

Only the hard-core solar purists say that systems must be totally naturally powered (that is, using natural convection, sky lids, or a solar chimney).

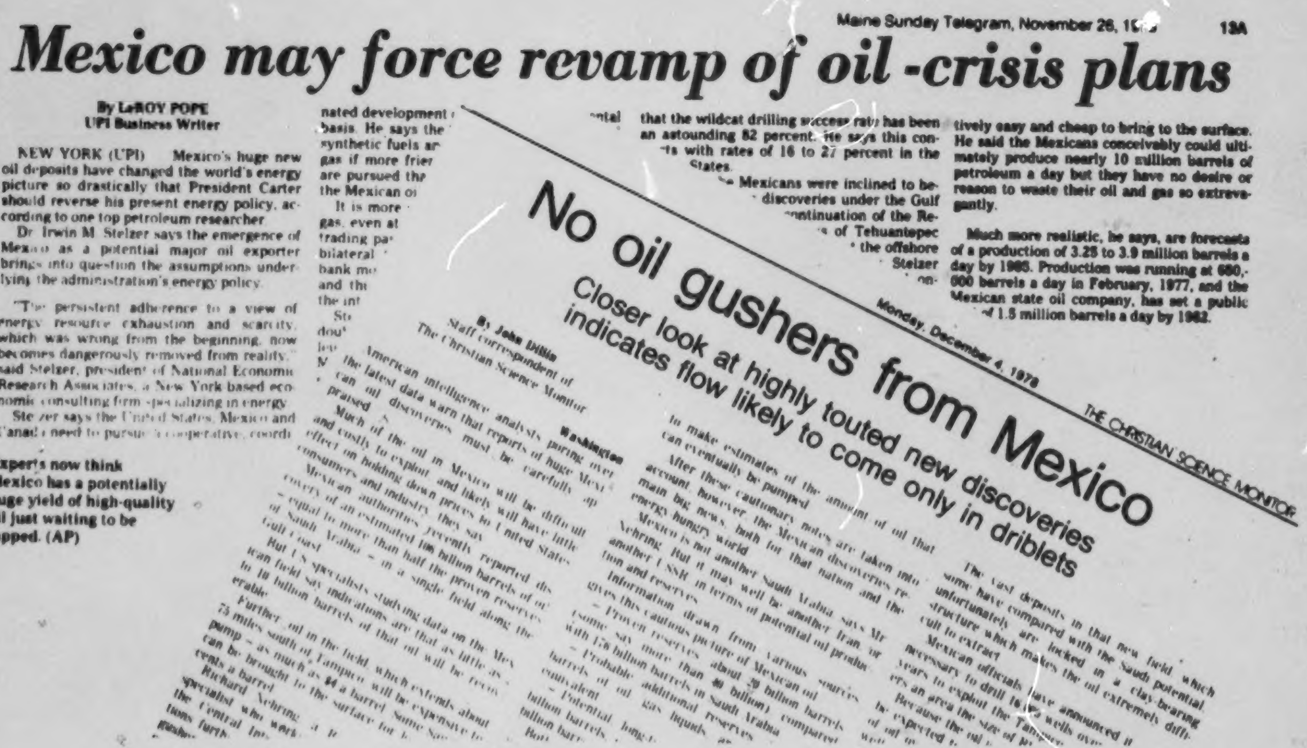
Designers have come up with an intermediate category called hybrid/passive that allows the use of some non-renewable energy -- a 1/20 horsepower fan to move warm air for instance. One solar expert calls for the following categories: if a system captures 50 times more energy than it uses, it can be considered passive; if 49-20 times more energy, it can be considered hybrid; if below 19 times, it can be considered active.

Doing a net energy analysis is vitally important. It may not be very efficient to go outside on a cold winter night to get more firewood if you lose most of your heat opening and closing the door. Expensive, energy-intensive, active solar systems are not always cost-effective.

CHAPTER TWO

RENEWABLE ENERGY SOURCES

Many Americans do not believe an energy crisis exists. People distrust the large oil companies as well as the oil exporting nations. Conflicting stories and claims appear in the press.



Maine Sunday Telegram, November 26, 19[illegible] 13A

Mexico may force revamp of oil -crisis plans

By LeROY POPE
UPI Business Writer

NEW YORK (UPI) Mexico's huge new oil deposits have changed the world's energy picture so drastically that President Carter should reverse his present energy policy, according to one top petroleum researcher.

Dr. Irwin M. Stelzer says the emergence of Mexico as a potential major oil exporter brings into question the assumptions underlying the administration's energy policy.

"The persistent adherence to a view of energy resource exhaustion and scarcity, which was wrong from the beginning, now becomes dangerously removed from reality," said Stelzer, president of National Economic Research Associates, a New York based economic consulting firm specializing in energy.

Stelzer says the United States, Mexico and Canada need to pursue a cooperative, coordinated development basis. He says the synthetic fuels ar gas if more frier are pursued the the Mexican oi

It is more gas, even at trading pa bilateral bank m and th the int

St dou lea N

that the wildcat drilling success rate has been an astounding 82 percent. He says this con- ts with rates of 16 to 27 percent in the States.

Mexicans were inclined to be- discoveries under the Gulf ontinuation of the Re- of Tehuantepec the offshore Stelzer on-

tively easy and cheap to bring to the surface. He said the Mexicans conceivably could ultimately produce nearly 10 million barrels of petroleum a day but they have no desire or reason to waste their oil and gas so extravagantly.

Much more realistic, he says, are forecasts of a production of 3.25 to 3.9 million barrels a day by 1985. Production was running at 680,000 barrels a day in February, 1977, and the Mexican state oil company, has set a public of 1.5 million barrels a day by 1982.

Experts now think Mexico has a potentially huge yield of high-quality oil just waiting to be tapped. (AP)

THE CHRISTIAN SCIENCE MONITOR Monday, December 4, 1978

No oil gushers from Mexico

Closer look at highly touted new discoveries indicates flow likely to come only in driblets

By John Dillin
Staff correspondent of
The Christian Science Monitor

Washington

American intelligence analysts poring over the latest data warn that reports of huge Mexican oil discoveries must be carefully appraised.

Much of the oil in Mexico will be difficult and costly to exploit and likely will have little effect on holding down prices to United States consumers and industry, they say.

Mexican authorities recently reported discovery of an estimated 100 billion barrels of oil – equal to more than half the proven reserves of Saudi Arabia – in a single field along the Gulf coast.

The magnitude of our nation's dependency on imported oil is poorly understood. A June 1977 Gallup Poll showed that 48% of all Americans did not know that we import oil at all![1]

This statistic is particularly alarming for the state of Maine when you consider the following facts: 76% of all the energy we consume in Maine is petroleum-based. 84% of this oil comes from foreign sources.[2]

The Governor's 1978 Comprehensive Energy Plan states: "(The latest data) finds Maine primarily dependent upon petroleum, a non-renewable and non-indigenous resource for energy ... Maine is much more dependent on petroleum than the rest of the nation. ... The situation has not improved since 1975, and has, in fact, deteriorated."[3]

RENEWABLE VS. NON-RENEWABLE RESOURCES

By definition renewable energy sources are those whose consumption can be approximately equal to the replacement capabilities of natural processes. These renewable resources fall into two rough categories:

Solar	Non-Solar
Thermal energy	Geothermal
Electricity (photo cells)	Tidal
Bio fuels (photosynthesis)	Nuclear fusion
Wind	
Hydropower	

These renewable energy sources can be distinguished from our current primary sources of supply: the fossil fuels coal, oil, and natural gas. The United States as a whole depends on fossil fuels for approximately 91% of its energy.

The fossil fuel dependence or addiction is one which could have serious economic repercussions, as the price of extracting the last increments of fuel becomes prohibitively expensive. By the turn of the 20th century, an orderly transition towards renewable energy resources must be well under way.

FOSSIL FUELS

Fossil fuels can be broadly classified as those naturally occurring non-renewable hydrocarbons such as coal, crude oil, or natural gas formed over extremely long periods of time from fossil remains of organic materials. Although fossil fuels are continuously being produced, the rate at which they are being used so greatly exceeds their fixation that they must be considered essentially non-renewable.

Fossil fuels have been an extremely attractive energy source because of the great amount of energy stored in a very small space. Per cubic foot, gasoline possesses about 10 times more BTU than wood. Because of this, oil and its derived products are excellent mobile fuels. The engineering problems of propelling an airplane on coal or wood are overwhelming to contemplate. Natural gas is an extremely clean fuel producing few harmful environmental effects upon combustion. These reasons, when coupled with their relative abundance, have made oil and gas the mainstay of our economy today, providing approximately 73% of our nation's energy budget. A close look at our energy sources reveals this extreme fossil fuel dependence.

COAL

Coal is the most abundant of the fossil fuels. It constitutes 90% of U.S. fossil fuel energy reserves, but currently supplies only 18% of our energy consumption. Coal can be broken down into three distinct types: bituminous (the major component), anthracite, and lignite. The latter may play the greatest role in our future energy needs despite its lesser fuel value because of its abundance in the western United States.

Coal is a complex and varied mixture of solid organic compounds. For this reason it is hard to generalize about coal as an energy resource. Its heating value, sulfur content, and ash properties vary widely. The National Energy Plan calls for increased use of coal over the next 50 years, to the extent that 30%-40% of our energy can come from coal. The environmental dangers of coal in use have been long known: black lung disease and sulfur dioxide air pollution are two widely documented side effects.

OIL

Currently 43% of the total U.S. energy comes from oil. World consumption of oil has grown at an annual rate of 6.6% since 1940 and as much as 8% annually during the 1960's. At a conjectural growth rate of 5%, the world's presently recoverable oil resources would be exhausted by 2010 -- that's 31 years. It is clear that the U.S. is looking toward an uncertain energy future with a spiralling energy demand. To maintain the world yearly consumption of 20 billion barrels of oil per year, a new Kuwait or Iran must be discovered every 3 years, or another Texas or Alaska every 6 months. The present level of oil consumption clearly cannot be sustained indefinitely.

In most discussions of energy reserves, "oil" refers to the total amount of petroleum liquids. Oil includes both crude oil as obtained from oil wells, and natural gas liquids, such as propane and butane obtained in the processing of natural gas. Because 40% of the oil we consume is used in our automobiles, it is essential that great attention be paid to making vehicles more fuel-efficient. Reducing gasoline consumption by car pooling, bicycling and walking is one method each individual can use to help ease our nation's growth in oil consumption.

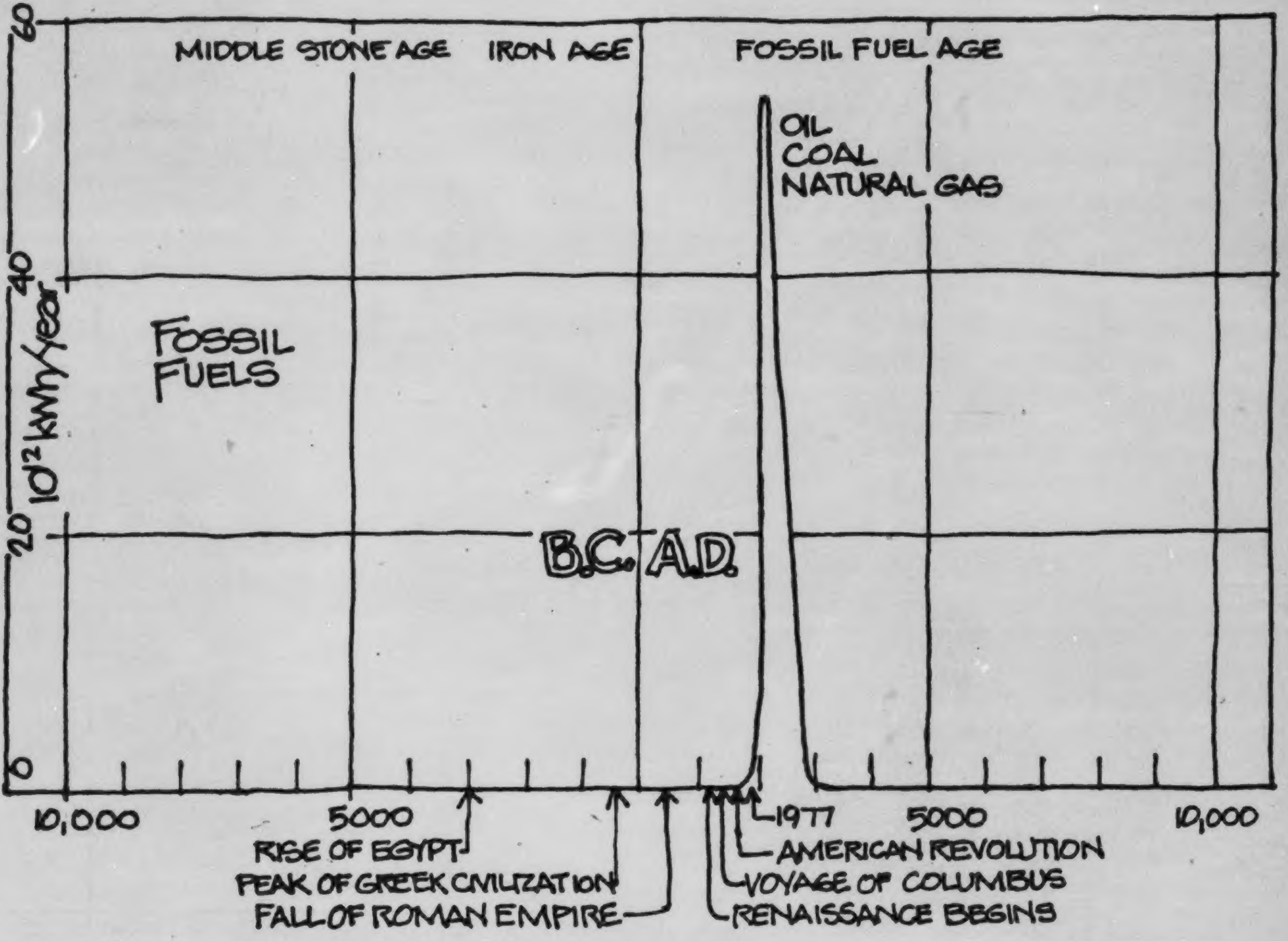
NATURAL GAS

In 1973 natural gas accounted for some 30% of U.S. energy consumption, yet it constitutes only 4% of domestic conventional energy reserves. Because the price of natural gas has been regulated, the true value of this energy source has been obscured. In 1976 natural gas in the interstate market sold at wellhead prices that were 25% of the BTU equivalent of imported crude oil. Most new onshore gas production has gone primarily into unregulated intrastate markets. It is estimated that gas from existing reservoirs will be able to supply only 55% of the demand by 1985. A decline in gas production is expected despite price increases. The difference between supply and demand will have to be met in part by increased importation of liquified natural gas, LNG. For most discussions, the term natural gas refers to "dry" natural gas, the substance remaining after the natural gas liquids have been removed.

OTHER SOURCES

In 1973, 97% of our energy need was met by the use of the three fossil fuels: coal, oil and natural gas. Two other sources provided the bulk of the remainder: hydropower and nuclear energy. In 1976, operating nuclear power plants provided approximately 10% of the U.S. electrical demand, or 3% of the total national energy budget.

Projections for future energy sources invariably include an accelerated input from nuclear energy. Because uranium is a finite resource and because no technologically safe breeder reactor has yet been developed, the nuclear fission power source, like fossil fuels, must be considered non-renewable. Persistent toxic wastes, thermal pollution, and potential terrorist activity all make nuclear power a dangerous energy source. Unlike low-technology, decentralized, renewable energy sources, nuclear power stations concentrate energy production in one location. The effect of a nuclear mishap on the electric grid may be likened to the death of a mule on a 20-mule team. Decentralization and diversification of our energy sources can forestall a massive brown- or black-out. As in nature, species diversification marks strength; so, too, in our search for new sources must we seek out a balance of alternatives.

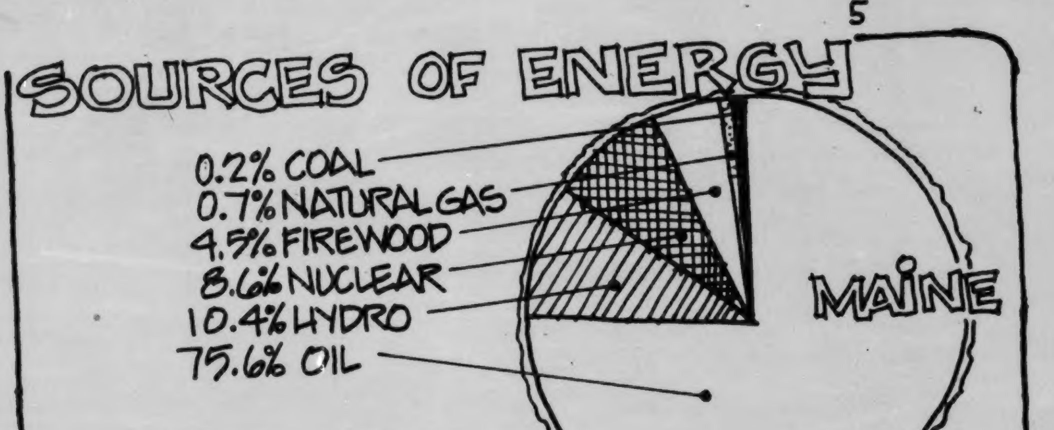


This graph depicts the rise and future sudden fall of the fossil fuel era. Experts at the Department of Energy in

Washington estimate that 80% of the world's oil reserves may be gone within a 65-year period.[4] How does this trend affect people living in Maine?

THE MAINE ENERGY SCENE

A brief comparison of Maine's energy supply pattern compared to that of the entire country follows:



Maine's dependence on oil is particularly alarming. Whereas most homes in the U.S. heat with natural gas, in Maine #2 heating oil is used over other energy forms by a wide margin. Furthermore, because Maine is predominantly a rural state with little mass transit, our gasoline consumption also is high on a per capita basis.

In short, various serious measures must be adopted in order for Maine to withdraw from its acute petroleum addiction. Solar energy and its cornerstone -- energy conservation -- can make a substantial contribution in creating this more diversified energy mix.

CONSERVATION AND SOLAR

The Governor's 1978 Comprehensive Energy Plan calls for a 3-tiered energy policy approach: 1) conservation, 2) diversification, and 3) native resource development.[6] Oil is a non-indigenous (or non-native) energy source to Maine. However the state does possess large undeveloped energy resources. These include solar, wood, bio-mass (peat and animal manures), hydro, wind, solid waste and tidal power. Little accurate data exists on the potential of each of these sources. The development of and switch to renewable energy sources will require substantial commitment of state and federal monies. However there is a growing movement in this direction as exemplified by the recently passed National Energy Act, which provides tax credits for solar and conservation purchases.

There are several excellent reasons why this switch to renewable energy sources makes sense, particularly for the construction industries. This switch can

- -- reduce the dependence on uncertain foreign oil;
- -- increase the level of disposable income on a household basis, since a lower percentage of a family's income will go to pay energy bills;
- -- create more jobs in retrofitting oil houses, installing solar systems, and developing other native resources;
- -- lessen the harmful impact on the environment and personal health because of lower levels of resource extraction and pollution.

Recent studies for the Northeast now show that investments in conservation and alternate energy resources would create 4-6 times more jobs than a comparable investment in nuclear generating facilities.[7] Likewise, numerous studies have shown the disastrous effect of spending massive amounts of dollars for mid-Eastern oil. It has been estimated that the OPEC nations will amass a cumulative surplus approaching $500 billion by 1980.[8] The international implications of this shift of economic power are dramatic.

ENERGY DEMAND

As the Gallup Poll referred to earlier stated, 48% of all Americans do not know we import oil. It may be this lack of understanding that has led to dramatic yearly increases in energy consumption in Maine.

As a region the Northeast suffers from energy prices 35% higher than the national average. Despite high energy costs, our overall energy consumption in Maine increased a whopping 7.8% in the period 1975-1976. The percentage of our state's energy that came from petroleum remained essentially the same. The overall amount of petroleum consumed, however, increased in total amount by 2½ million barrels. These statistics led the Office of Energy Resources in Augusta to conclude that our energy situation with respect to vulnerable, imported oil has not improved but rather "deteriorated". Thermostats creep back up towards 70°F., drivers ignore the 55 mph speed limit. America is back to business as usual.

EXPONENTIAL GROWTH

The implications of a 7.8% annual increase in consumption are poorly understood. The phenomenon of exponential growth -- that is, growth at a geometric rate -- enters the picture.

A function is exponential if it increases by the same multiplicative factor in equal intervals of time. In an exponential function, the last term exceeds the cumulative total, e.g. in the series 1,2,4,8,16, 16 is greater than 8+4+2+1.

This increase in energy consumption may have harmful side effects on the environment which we cannot now foresee. It has been suggested that if the demand for electricity continues to double every ten years, the crucial factor may prove to be not the supply of fuels, but rather the build-up of CO_2 and the resulting climatic changes. There is simply no way to provide for an exponentially increasing demand on finite resources.

DOUBLING TIMES FOR VARIOUS RATES OF EXPONENTIAL GROWTH

Percentage increase per unit time	Doubling time
0	infinite
1	69.7
2	35.0
3	23.4
4	17.7
5	14.2
6	11.9
7	10.2
8	9.0
9	8.0
10	7.3
20	3.8
30	2.6
40	2.1
50	1.7

A rough rule of thumb for doubling time is:

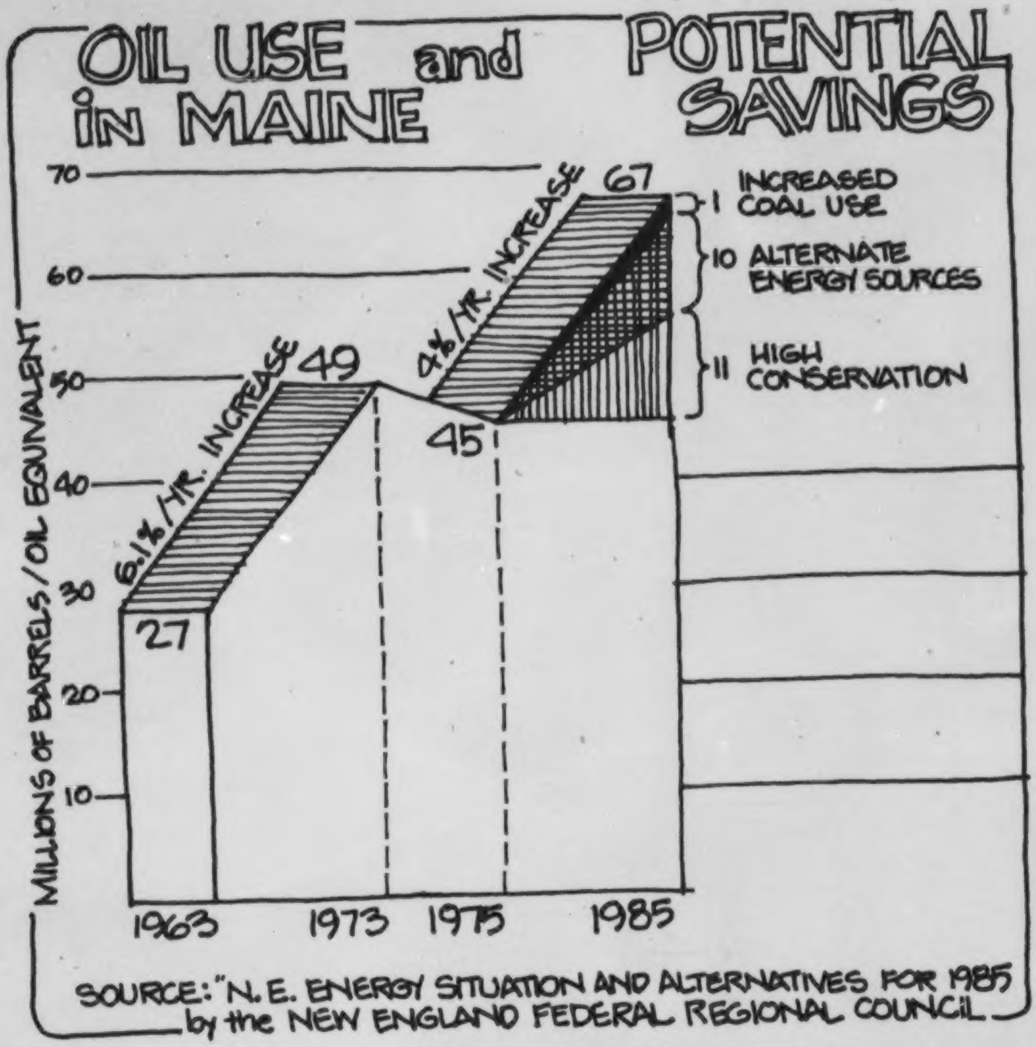
$$\text{doubling time} \approx \frac{70 \text{ years}}{\% \text{ annual increase}}$$

Thus we can see that if exponential growth continues at 7.8%, we will be forced to double our production facilities, double our extraction of energy resources, and double our pollution in a mere 9-10 years. This rapid rate could be slowed by the widespread use of energy conservation and solar technologies.

IMPACT OF CONSERVATION

In 1975 oil use in Maine totaled 45 million barrels. If we conservatively assume a 4% increase in oil consumption per year, then in 1985 oil use will amount to 67 million barrels. Will those oil resources be there to supply our needs?

The New England Federal Regional Council issued a report which argues that this high level of consumption can be substantially reduced. They conclude that the following three actions --1) high conservation, 2) alternate energy sources, and 3) increased coal use -- can maintain our current (1975) use of oil through 1985.[9] The breakdown is as follows in the graph on the next page:



OIL USE in MAINE and POTENTIAL SAVINGS

SOURCE: "N. E. ENERGY SITUATION AND ALTERNATIVES FOR 1985 by the NEW ENGLAND FEDERAL REGIONAL COUNCIL

The graph demonstrates that between 1973 and 1975 our consumption of oil actually dropped. The Oil Embargo forced us to do some dramatic belt tightening. If we assume a 40% per annum increase in energy consumption, then we as a state will require about 67 million barrels of oil in 1985 -- or its equivalent. This energy requirement can be satisfied in part by the use of four major alternative sources. The Regional Council quantified the potential of each:

	Millions of barrels equivalent in 1985
Wood utilization	7.1
Reclaimed hydro	2.7
Solar	.1
Solid waste	.1
total	10.0

THE SOLAR POTENTIAL

In November 1978 the New England Energy Congress issued its Preliminary Report for Public Review.[10] This Congress was composed of 120 carefully screened delegates representing business, utilities, state and local governments, environmental and social service organizations. The Congress worked for a full six months to pull together recommendations for legislation for the New England Congressional Caucus.

In their chapter assessing the potential contribution of solar to New England's supply mix, they conclude, "There are widely divergent views concerning the contribution that solar energy could make to the United States supply mix through the year 2025." For the year 1985 there is a difference in opinion by a magnitude of 25.[11] The Mitre Corporation predicts a solar contribution equal to 36 million barrels of oil per year, while Amory Lovins predicts a 900 million barrel contribution.

The extent to which either projection becomes a reality will depend to a certain extent on the effective development and implementation of solar energy programs within the public schools. Trained, energy-literate technicians will be essential for solar to have large scale impact.

The Supply Committee of the New England Energy Congress recommends legislative actions that will result in the following:[12] For New England in the years 1979-1989,

- -- $22.6 billion expended over 10 years on solar applications,
- -- 11% of the solar installations nationwide to be in New England, resulting in 2,000,000 systems by 1989,
- -- 194 million square feet of collectors installed.

To a large extent the potential impact of energy conservation and solar energy will depend on political actions. What will become of the New England Energy Congress's recommendations? Citizen awareness of key energy issues and grassroots political organizing will help shape Maine's energy future.

FOOTNOTES

1. Smith, Ralph Stuart, "The United States and World Energy," a discussion paper, Department of State, publication # 8904, General Foreign Policy Series 304, November 1977, Office of Media Services, Department of State, Washington, D.C., page 3.

2. Maine Office of Energy Resources, Maine Comprehensive Energy Plan -- 1978 edition, 55 Capitol Street, Augusta, Maine, page 2.

3. Ibid., page 52.

4. Department of Energy, traveling energy van display entitled "Oil", visited Portland, Maine, Oct. 6, 1978.

5. Maine Office of Energy Resources, op. cit., page 43.

6. Ibid., page 62.

7. Solar Age, August 1978, "Nuclear and Solar: Employment, Economics and Society", entire issue devoted to these issues. Also see: New England Energy Congress Subcommittee on Jobs, proceedings of testimony delivered at Portland, Maine, Oct. 10, 1978.

8. Eastler, Dr. Thomas, environmental geologist, UMF, Farmington, Maine, "End of the Fossil Fuel Era", reprint of a talk available from Equifax, Inc., 1600 Peachtree Street, Atlanta, Ga 30309.

9. Maine Office of Energy Resources, op. cit., page 60.

10. New England Energy Congress, "Preliminary Report for Public Review", November 1978, Tufts University, Medford, Mass.

11. Ibid., page 108.

12. Ibid., page 19.

CHAPTER THREE

HISTORY OF SOLAR

It is a mistake to label the solar technologies as alternative energy resources. They are the steady, natural, time-proven energy forces that have powered our planet for billions of years. It is the nuclear and petroleum technologies which are unnatural and alternative. The by-products of those technologies place great stress on the natural environment, e.g. scarred strip mined landscapes, polluted air and beaches, toxic radioactive wastes.

Three major concepts must be understood in looking at the history of solar:

1) Basic solar principles have been understood and applied for decades.
2) The federal government and large businesses have invested heavily in petroleum and nuclear technologies at the expense of solar development.
3) There is a time lag before any new technology can replace a previous one, i.e. solar energy research, demonstration and education must begin now if their input is to be significant in the mid-1980's.

SOLAR THROUGHOUT HISTORY

Examples of ingenious solar applications occur throughout recorded history. Several of the most eye catching are:

1) In 212 B.C. Archimedes used solar reflecting mirrors to set fire to the sails of the attacking Roman fleet at Syracuse.

2) In 1780 Antoine Lavoisier, the inventor of the guillotine, discoverer of oxygen, and principal architect of the metric system, used a 52"-diameter glass lens to melt platinum at a temperature of more than 3100°F. in his solar furnace.

3) By 1900 one company in Los Angeles had installed more than 1600 solar hot water heaters.

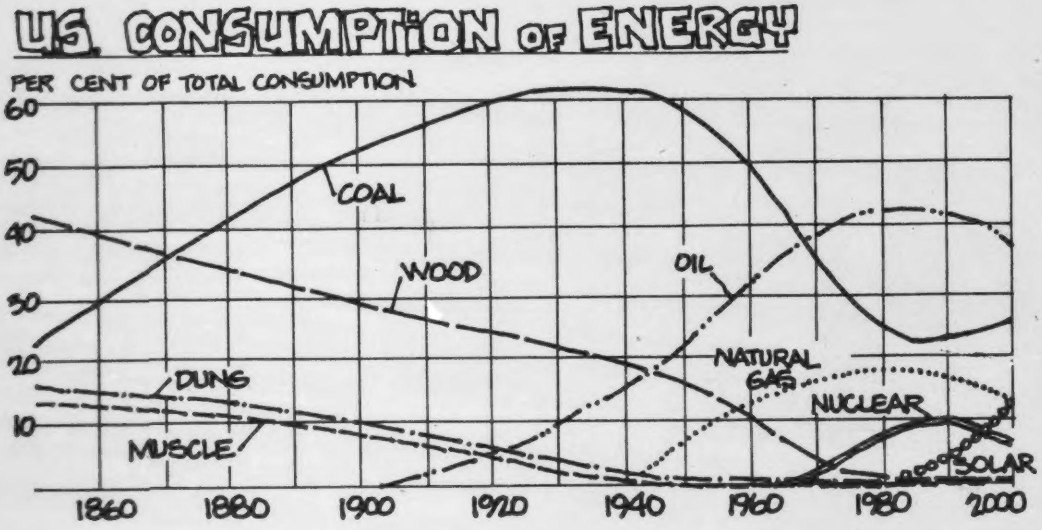
4) In 1907 Frank Shuman designed a flat plate collector system which ran a test engine producing 3.5 horsepower. The system used ether to drive a steam engine which pumped water.

5) In 1933 Chicago World's Fair architects George and William Keck designed a direct gain southern glass passive solar house.

6) In 1965 NASA used millions of photo-voltaic cells to power satellites.

Solar technologies for both generation of heat and electricity have been around for some time. The availability of cheap alternative fuels such as natural gas and oil has discouraged throughout history the further development of particular solar technologies. As these fossil fuels diminish in quantity and as research is applied to solar technologies, many of these "age-old" solar ideas will be reborn.

The time line illustration explains how one fuel resource has replaced another. Many Maine oil dealers have gone through a similar business evolution. One oil company has switched from wood to coal to oil as its principal fuel during the last 90 years. This same company is now training its workers in energy conservation and solar technologies.



There exists a time lag for technology replacement, estimated to be between 20-40 years. For example, it took about 40 years for commercial aviation to become a major industry (1903-1940). It has taken computers 30 years to reach the home market. Video recording equipment has undergone a miraculous evolution in the past ten years.

However, the switch from one energy source to another may not be as easy: after 30 years of massive federal subsidies, nuclear power still contributes less than 2% of our energy needs. The fact that solar has had a sporadic but prior history can be to its advantage.

With fossil fuel supplies uncertain, it is essential that the shift towards renewable energy sources take place immediately. One of the major costs of solar technology is its installation. Without trained system designers, installers and technicians, the most advanced high-technology equipment is useless. Because much trial and error experimentation has had to take place, the first several years of solar installation have been trying. Solar education must become a high national priority immediately.

HISTORICAL VALUES

There was a time when a family was evaluated by its degree of self-reliance and preparedness, e.g. if the next year's wood supply was cut and drying, if sufficient food had been put by for the winter. Self-reliance necessitated living in tune with natural energy cycles. Less was more.

Today, we expect unlimited power to be delivered to us year-round at the flip of a switch. American society relies more and more on electrical energy.

Far too few people ask what is the true price we pay for the instant power we demand. Our energy-intensive lifestyle blinds us to opportunities for re-tapping natural energy flows, the energy we have relied on for most of our existence here on earth.

Returning to natural energy sources re-kindles an awareness of natural forms and patterns. Nature's majesty suggests new solar technologies, e.g. the parabolic concentrator that is the horseshoe crab's eye, the irridescence of the abalone shell with its optical layers, the absorptive cooling of an elephant's ears, the down insulation of migrating water fowl.

Denis Hayes states: "Every technology embodies the values and conditions of the society it was designed to serve." The fact that we as a society choose to "power our way out" of the energy crisis with increased coal and nuclear power suggests that we have been estranged from natural energy flows. Heating with wood can be physically invigorating, aesthetically pleasing and economically justifiable. Solar energy is not the number one alternative energy source; it is the number one natural energy source. Our technology has created the alternatives.

CHAPTER FOUR

QUANTIFYING THE SOLAR RESOURCE: IS THERE ENOUGH?

Solar energy is the principal driving force of our planet. In one year the amount of solar energy striking the earth is five thousand times the combined total of all other energy sources.

Despite its overabundance, solar energy cannot meet our total world energy demand. Solar is intermittent. It falls in remote places. It is delivered to us in unconcentrated forms. The trick in making solar a viable energy resource lies in matching particular solar processes to specific applications, i.e. use high entropy, diffuse solar energy for low quality energy tasks like solar wood dryers.

Solar energy will make a substantial contribution to our energy budget in the heating and cooling of structures, in the heating of water for domestic purposes, in agricultural applications, in industrial processes, and in the generation of electricity. The magnitude of solar's contribution will depend on the mobilization of political support for renewable energy resources, the re-channeling of research and development funds, and, most importantly, the level of energy awareness of the American people.

SUN FACTS

Consider the following sun facts:

-- In Maine while the sun is shining, the energy equivalent of a gallon of gasoline falls in an area the size of a tennis court about every 15 minutes.

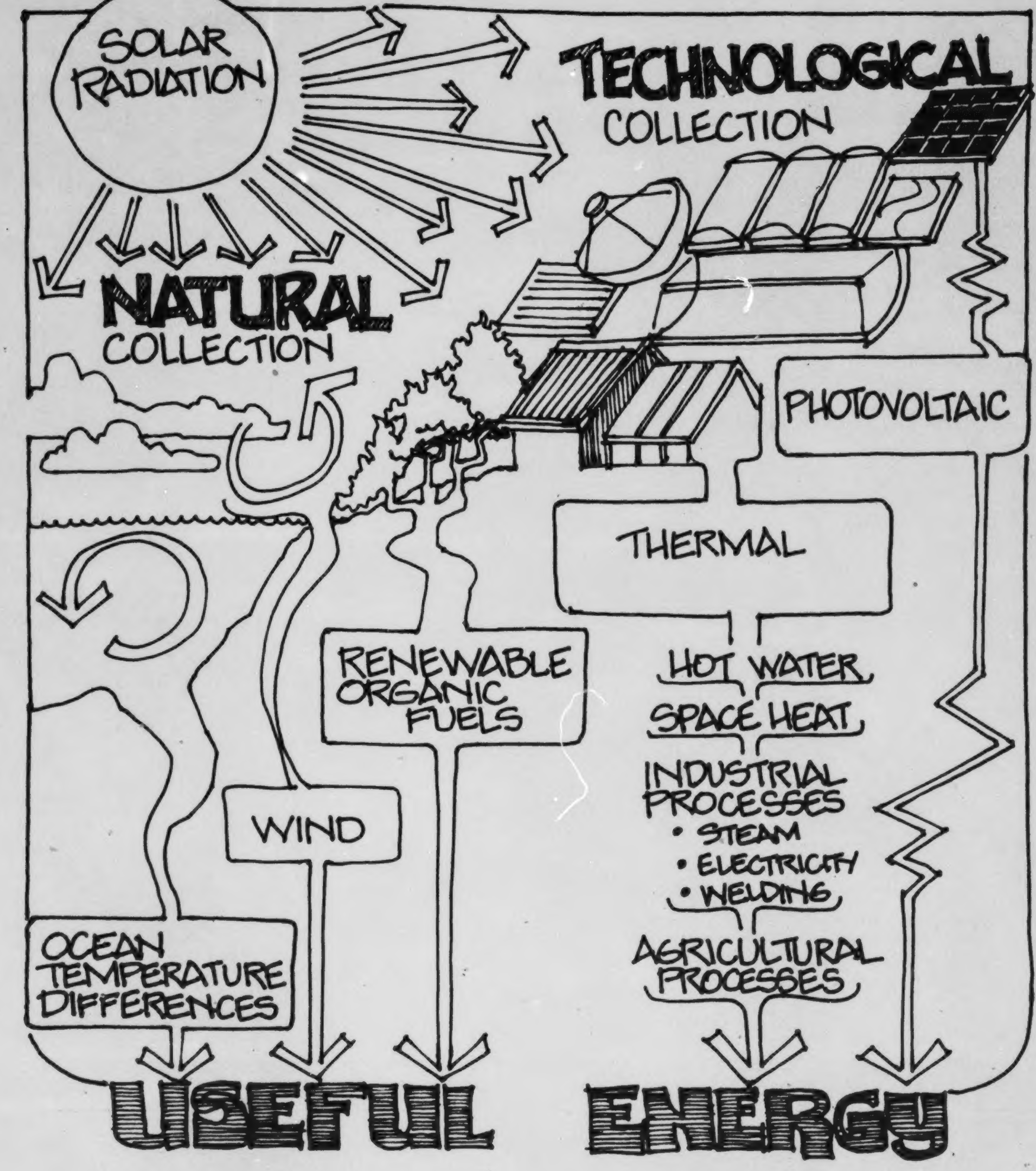
-- The solar energy striking a football field in Portland during the course of one hour near noontime on June 21 is equal to the energy equivalent of about 285 kilos (625 lbs.) of coal.

-- The solar furnace in Odeillo, France, can achieve temperatures in excess of 6700°F.

-- The total solar energy striking the United States in one year is equal to 1 million times the energy output of an average electric power plant.

Clearly, enough solar energy reaches the earth to make it a significant resource. However, much of that energy strikes the earth in remote, inaccessible places. 71% of the surface area of the globe is covered by water. Although solar energy itself is free, the inexpensive capture and efficient use of this renewable resource challenges all designers.

Solar energy can be used in two basic ways: the natural and the technological.


SOLAR RADIATION
TECHNOLOGICAL
COLLECTION
NATURAL
COLLECTION
PHOTOVOLTAIC
THERMAL
RENEWABLE ORGANIC FUELS
HOT WATER
SPACE HEAT
INDUSTRIAL PROCESSES
• STEAM
• ELECTRICITY
• WELDING
AGRICULTURAL PROCESSES
WIND
OCEAN TEMPERATURE DIFFERENCES
USEFUL ENERGY

A variety of opinions exist as to the magnitude of potential solar application. How much can solar be expected to contribute and when? In 1975 the Energy Research and Development Administration (ERDA) suggested the following breakdown nationally:

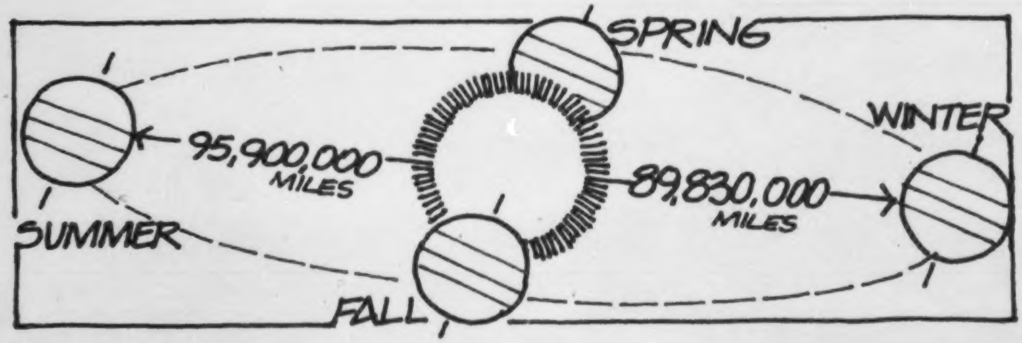
	1985	2000	2020
Solar Thermal in quadrillion (10^{15}) BTU			
Heating and cooling	.15q	2.0	15
Agriculture applications	.03q	.6	3
Industrial applications	.02q	.4	2
	.2q	3.0q	20q
Solar Electric in GigaWatts electric (GWe) or 10^9 W			
Wind	10	20	60
Photovoltaic	.1	30	80
Solar thermal	.05	20	70
Ocean thermal	.1	10	40
	1.3GWe	80GWe	250GWe
Equivalent fuel	.07q	5q	15q
Solar bio-mass	.5q	3q	10q
Total solar energy	1.0q	11q	45q
Projected U.S. demand	100.0q	150q	180q
% Solar	1%	6.6%	25%

Two key assumptions need to be questioned: 1) can we afford to wait until the year 2000 before solar technologies seriously begin to enter into the energy supply picture? 2) Can we control the rate of United States energy demand so that we do not require 100 quadrillion BTU by 1985? In 1973 the state of Iowa used a total of about 1 quadrillion BTU. The U.S. consumption for 1977 was about 85 quadrillion BTU.

Despite these fairly impressive "Sun Facts", there exist certain yearly averages which can set an upper limit on what we can expect from the sun. It is always important to remember that energy conservation and solar go hand-in-hand. Once we become more energy aware, the percentage of our energy budget that can come from the sun can go up quickly.

THE SOLAR CONSTANT

Energy travels through space from the sun to the earth. The distance the energy must travel varies with the time of the year due to the elliptical orbit of the earth.



The sun is actually closer to the earth in the winter than in the summer. This difference in distance produces a fluctuation in the amount of solar radiation striking the earth's outer atmosphere. In June the earth receives 413 BTU/ft.^{2}-hour, while in December the earth receives 441 BTU/ft.^{2}-hour. The intensity of radiation is a function of distance from the source. Averaged out over the course of the year, the earth is bathed in sunlight at the rate of 429 BTU/ft.^{2}-hour. This quantity is defined as the Solar Constant.

Question: if the earth is closer to the sun in the winter than in the summer, why is it cold in the winter in the northern hemisphere?

Answer: although it is true that more energy strikes the earth's outer atmosphere in December than in June, the seasonal tilt of the earth lessens the amount of useful solar energy that strikes the earth's surface in the northern hemisphere.

QUALITY OF ATMOSPHERE

The amount of solar radiation that reaches the earth's surface is extremely variable: it ranges from 0-50% of the energy available at the earth's outer atmosphere. The quality of the atmosphere is a determining factor in the amount of insolation (incident solar radiation) reaching the earth's surface. Clouds, water vapor and carbon dioxide in the atmosphere will absorb and emit infrared radiation. The presence of these factors during daylight hours will reduce the amount of insolation during the day. At night these factors will reduce the amount of heat that is lost to the outer atmosphere by providing a cover. The amount of usable energy is restricted still further by the efficiency of our means of conversion.

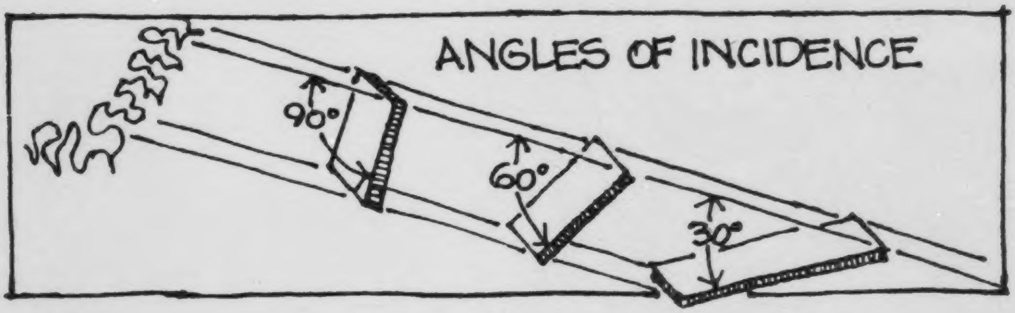
Radiation that reaches the earth's surface can be categorized as either direct or diffuse. Direct radiation comes to us in parallel rays, undeflected by the earth's atmosphere. Diffuse radiation is multi-directional, having been reflected from clouds and atmospheric dust.

On a cloudy day, up to 80% more energy is reflected and absorbed by the atmosphere. Carbon dioxide, a by-product of respiration and combustion, strongly absorbs radiation in certain bands of the infrared. Air pollution caused by smoke, dust and chemical particles can further reduce the amount of incoming solar radiation.

Geography also affects the amount of solar energy that is absorbed by the atmosphere. Ocean areas, snow covered regions, and deserts reflect more incident solar energy back to space.

SOLAR ANGLES

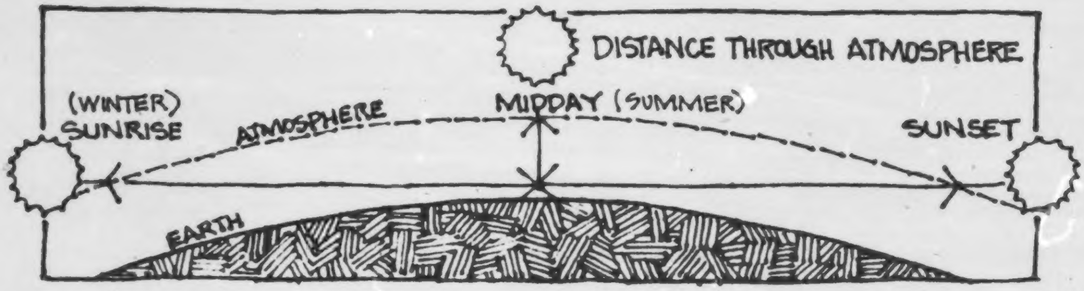
The angle of the sun's rays relative to the earth's surface determines the intensity of the rays. The energy received from the sun is most intense when the rays strike the earth most vertically, thereby traversing the minimum distance through the atmosphere. This occurs around midday. The angle of incidence (the angle between the direction of the sun and the perpendicular to the surface on which it is falling) determines the intensity of the sun's rays on the surface. The intensity on a surface decreases as the incident angle increases because the same amount of light is spread over a larger area.



The angle of incidence at any given site is determined by the altitude and azimuth angles of the sun.

Explanation:

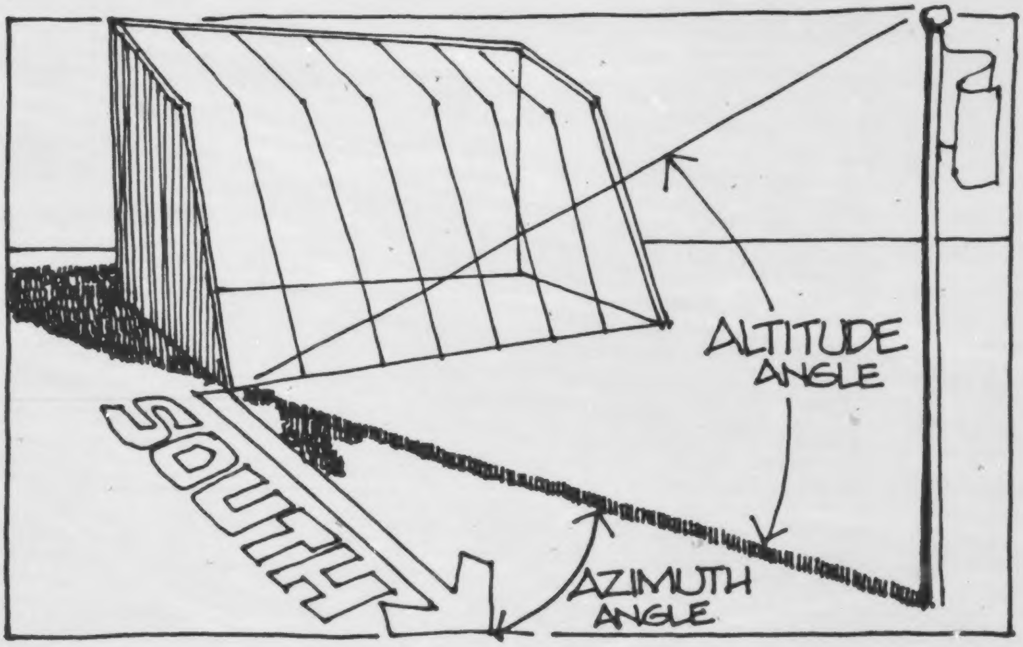
1. If the sun's rays are most vertical at midday, then it follows that the angle of incidence is lowest at sunrise and sunset.


DISTANCE THROUGH ATMOSPHERE
(WINTER) SUNRISE
ATMOSPHERE
MIDDAY (SUMMER)
SUNSET
EARTH

2. The light at sunrise and sunset (and all the time on either side of midday) must travel a greater distance through the atmosphere than it travels at midday. The farther light must travel through the atmosphere, the greater the chance that the energy will be reflected or absorbed by molecules in the air.

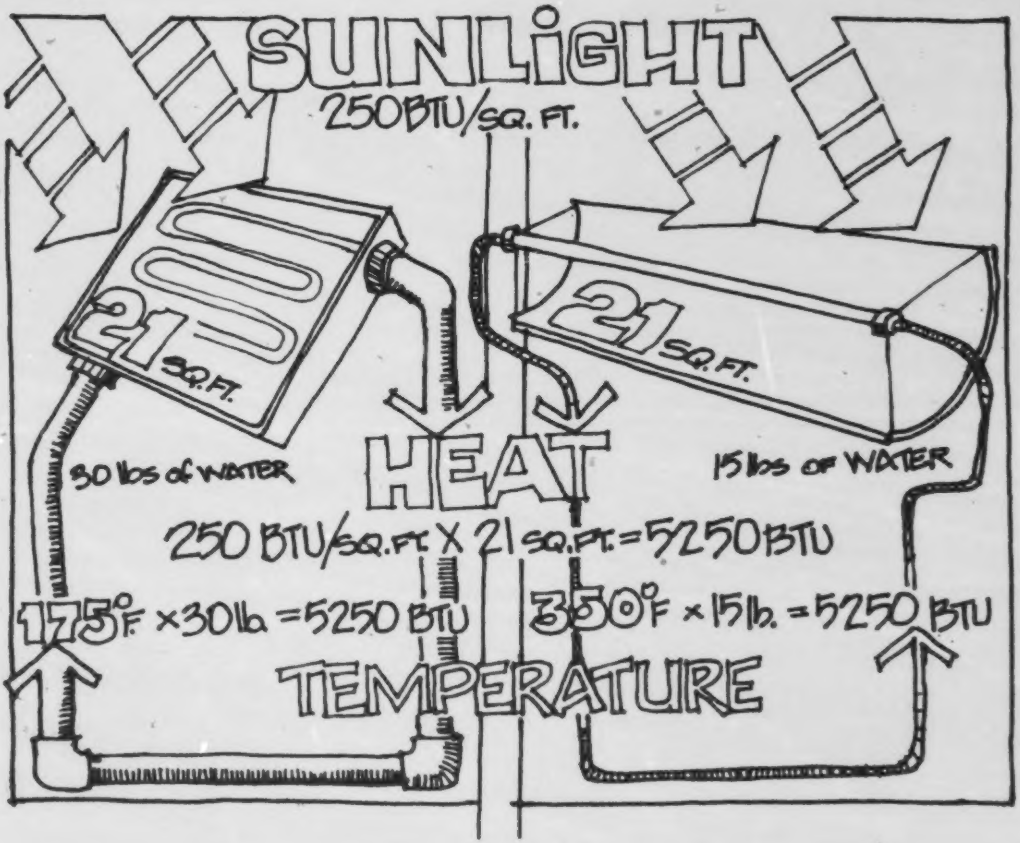
3. Altitude angle is the angle of the sun above the horizon. In Maine, which ranges from 43°-47° North latitude, we experience the sun (assume 44° N latitude to be average population-wise) at a maximum altitude angle of 70° on June 21st and a minimum angle of 23° on December 21st. In Maine we never receive direct, overhead solar radiation.

4. Azimuth angle refers to the angle of the sun relative to the true north/south line. A collector facing due south has an azimuth angle of 0°. Generally speaking, an azimuth angle of 0° will provide maximum insolation. However, a 15° east or west variation is not critical.


SOUTH
ALTITUDE ANGLE
AZIMUTH ANGLE

KEY SOLAR PRINCIPLES

You cannot increase the amount of solar energy striking collectors of equal glazing by focusing. In other words, if we build two collectors of equal glazing surface area, one a flat plate collector and the other a linear parabolic concentrator, each unit will have equal heat generating capabilities. Although the temperature of the exchange fluid will be higher in the concentrator, the amount of heat each collector can extract will be equal because the amount of energy received is the same.


SUNLIGHT
250 BTU/SQ. FT.
21 SQ.FT.
21 SQ.FT.
30 lbs of WATER
HEAT
15 lbs OF WATER
250 BTU/SQ.FT. X 21 SQ.FT. = 5250 BTU
175°F × 30 lb. = 5250 BTU
350°F × 15 lb. = 5250 BTU
TEMPERATURE

SOLAR TEMPERING

The concept of solar tempering is often misunderstood. Tempering means using solar energy to lower your energy bill. For example, domestic hot water heating can be done by solar on a cost-effective basis today. It is not essential that 100% of a household's hot water be heated by solar. A 60% contribution in the winter and a 95% contribution in the summer represent cost-effective solar tempering. The same goes for solar space heating. A passively heated solar house can get 50%-60% of its requirements from the wise placement of windows and the intelligent use of insulation. A solar tempered house can then be heated with a small amount of wood as a back-up. Achieving 100% solar heat is an expensive proposition.

CHAPTER FIVE

HEAT TRANSFER

To capture, store and distribute heat is the ultimate goal of every solar thermal energy system. A basic understanding of how heat is transferred is essential for quality solar design.

Heat or thermal energy is transferred by three basic methods: conduction, convection and radiation. There are detailed equations which describe in theory how heat travels. However, it is laboratory testing which gives us the R-value, or measure of thermal resistance, for specific substances. The R-value is a "performance rating" in that it takes into consideration in a general way how heat is transferred through a material or a building's cross-section by all three methods of heat transfer.

CONDUCTION

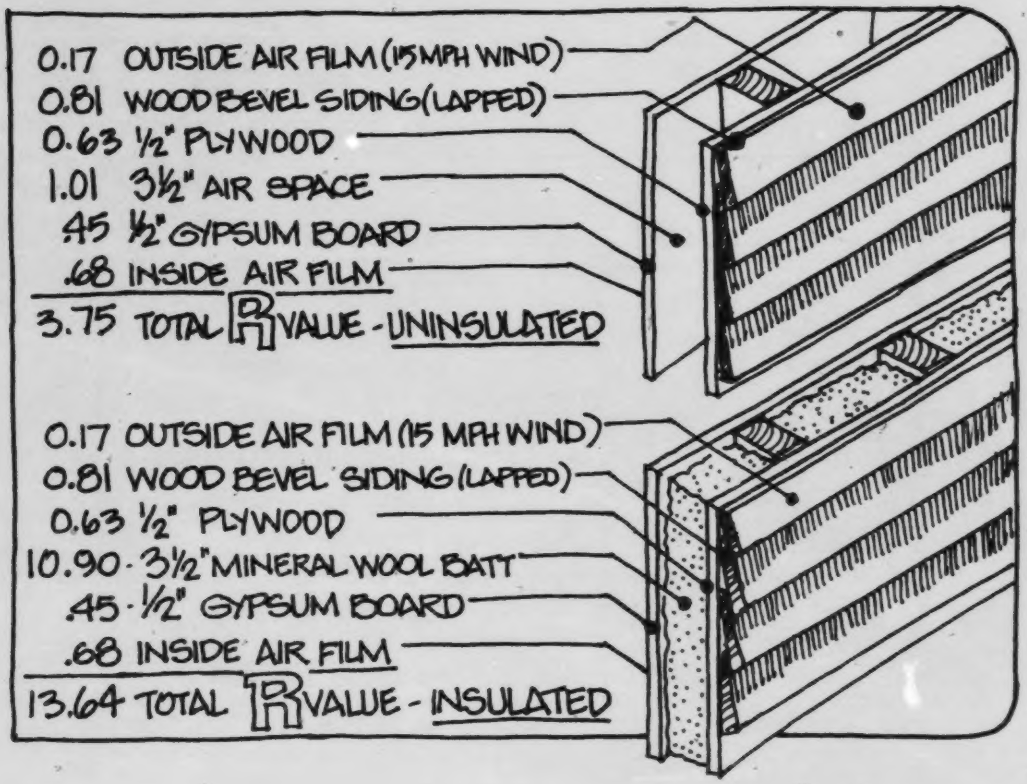
On a microscopic level, the atoms or molecules are bumping into one another when conduction heat exchange occurs. It is heat transfer by conduction that causes the handle of an iron frying pan to heat up on the stove. Generally speaking, materials which are good electrical conductors will also be good thermal conductors. Substances with low R-values are generally termed insulators; materials with high R-values offer high thermal resistance. Some typical R-values follow:

RESISTANCES OF COMMON BUILDING MATERIALS

Material	Thickness	R-value $\frac{ft^2 \cdot {}^\circ F \cdot hr}{BTU}$
Brick	4"	0.80
Cellulose fiber	1"	3.70
Concrete	1"	0.08
Concrete blocks (cinder)	8"	1.72
Fiberglass roof insulation	1"	3.94
Hardwood	3/4"	0.68
Softwood	3/4"	0.94
Styrofoam sm	1"	5.26

R-VALUES

Thermal resistance is a measure of a material's tendency to retard heat flow. R-values are cumulative, i.e. the component pieces of a building's cross-section all have specific R-values which can be summed to give the total R-value of that particular section of the house. The R-value of a conventional wall is the sum of the R-values of the separate parts of that wall.

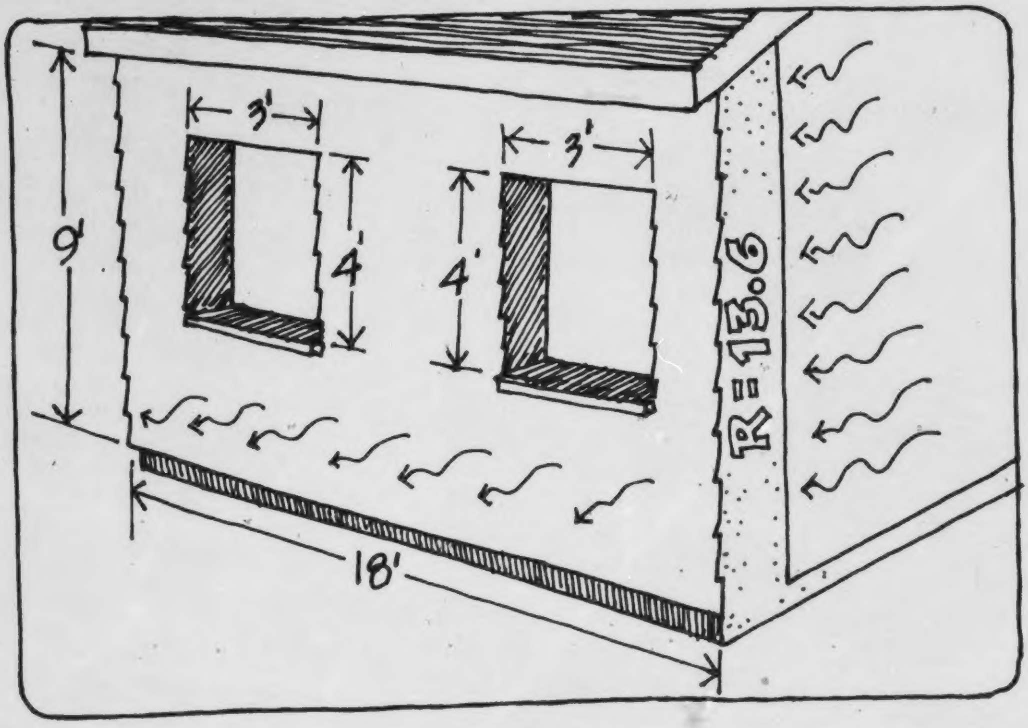

0.17 OUTSIDE AIR FILM (15 MPH WIND)
0.81 WOOD BEVEL SIDING (LAPPED)
0.63 1/2" PLYWOOD
1.01 3 1/2" AIR SPACE
.45 1/2" GYPSUM BOARD
.68 INSIDE AIR FILM
3.75 TOTAL R VALUE - UNINSULATED
0.17 OUTSIDE AIR FILM (15 MPH WIND)
0.81 WOOD BEVEL SIDING (LAPPED)
0.63 1/2" PLYWOOD
10.90 · 3 1/2" MINERAL WOOL BATT
.45 · 1/2" GYPSUM BOARD
.68 INSIDE AIR FILM
13.64 TOTAL R VALUE - INSULATED

R-values carry the units $\frac{ft^2 \cdot {}^\circ F. \cdot hr.}{BTU}$. Once the total R-value of a building section is known, the heat loss due to conduction can be figured using the following formula:

$$H_{cond} = \frac{Area \times \Delta T}{R}$$

where Area = the area of that particular building cross-section in square feet; ΔT = (Tin - Tout); and R = total R-value for that building section.

Take, for example, the R-13.6 wall described above. Compute the heat loss through that wall over the course of an hour, a day, and the heating season.



The total surface area of the wall =

18" x 9" - (window areas)

18" x 9" - [2(4'x3')] =

162' - (24)' = 138 square feet of R-13.6 wall

$$H_{conduction} = \frac{A \times \Delta T}{R}$$

$$H_{conduction} = \frac{138\ ft^2 \times (65-25^{o}F.)}{13.6} = 405.9\ BTU/hr$$

To compute the heat loss by conduction for a day, we compute:

$$H_{day} = BTU/hr \times 24hr = \frac{24 \times Area \times \Delta T}{R}$$

$$H_{day} = 405.9\ BTU/hr \times 24\ hr =$$

$$9741.6\ BTU/day$$

To compute the heat loss for an entire heating season we utilize the concept of Degree-Days.

DEGREE-DAYS

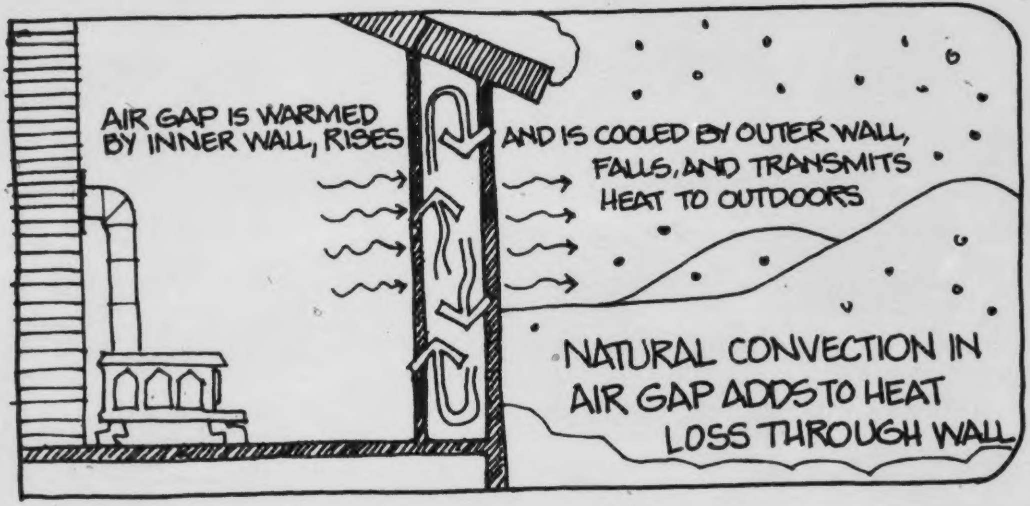
The number of Degree-Days (DD) is defined as the sum of the daily differences in average indoor (65^{o}F. base) and outdoor temperatures over the course of a heating season. For example, if the average outdoor temperature for one day is 25^{o}F., then $65^{o}-25^{o}$, or 40 Degree-Days have accumulated for that one day. Brunswick, Maine, accumulates about 7600 Degree-Days per heating season, Caribou about 9800. Degree-Days are a measure of days and ΔT's. Therefore,

$$H_{annual} = \frac{24 \times Area \times DD}{R}$$

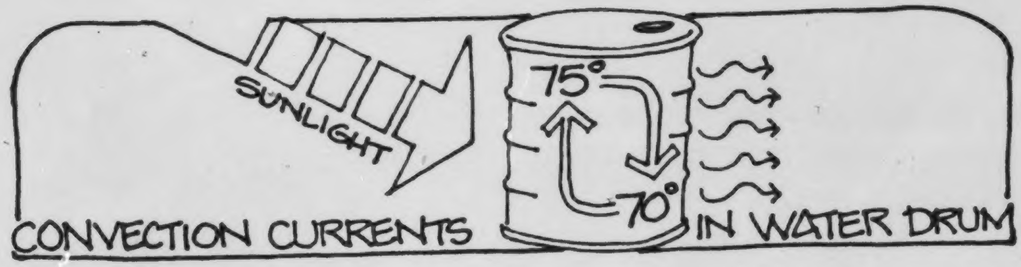
CONVECTION

In the determination of R-values, all three forms of heat transfer are considered. The most important, however, is conduction. Of secondary importance is the heat loss due to convection. Convection is the transfer of heat by the movement of a fluid, usually air or water. As the transfer fluid is heated up by conduction, it "carries" the heat away.

A fan placed behind a wood stove will convect warm air to other parts of a room. Natural convection occurs within uninsulated walls as air is warmed and rises along the warm inside wall and drops as it loses heat to the cool outside wall.


AIR GAP IS WARMED BY INNER WALL, RISES
AND IS COOLED BY OUTER WALL, FALLS, AND TRANSMITS HEAT TO OUTDOORS
NATURAL CONVECTION IN AIR GAP ADDS TO HEAT LOSS THROUGH WALL

Convection also occurs within the water in a 55-gallon drum inside a greenhouse.


SUNLIGHT
75°
70°
CONVECTION CURRENTS
IN WATER DRUM

As the sun strikes the black outside surface, heat is transferred to the water molecules. The heated molecules rise, causing the water to circulate.

INFILTRATION HEAT LOSS

In computing heat loss, engineers consider only two measurable phenomena: conduction and infiltration. Infiltration is defined as the uncontrolled exchange of inside with outside air. Unlike the analyses of conduction heat loss, infiltration heat loss requires sophisticated guesswork. Three separate infiltration calculations were made for the Maine Audubon Society's new solar building. The air exchange rates differed as much as 50%.

The following general rule of thumb can be used:

2-3 air exchanges (AE) per hour - a drafty, uninsulated house
1 AE/hour - a standard insulated new house
1/2 AE/hour - a tightly constructed, energy-efficient house

It is necessary to guess the air exchange rate in order to calculate the annual heating load.

The following "Heat Loss/Heat Gain Ledger" can be used to perform a thermal analysis on any conventional house. Fill out the heat balance sheet as follows:

1) List all surface areas of various house sections. The distinction is made between day and night window values, to allow for a change in R-value if insulating window materials are used.

2) Determine R-values from standard ASHRAE tables. Use the infiltration rate guessed at by intelligent inspection.

3) Complete table. Assume a ΔT of 40F.°

HEAT LOSS/HEAT GAIN LEDGER

HEAT LOSS

SECTION	AREA, S.F.	R-FACTOR	A/R	$H_{HR} =$ $A/R \cdot \Delta T_{MAX}$	$H_{DAY} =$ $A/R \cdot 24 \cdot \Delta T$	$H_{ANNUAL} =$ $A/R \cdot 24 \cdot DD$
FLOOR						
ROOF						
SOLID WALL						
DOOR						
WINDOW, DAY*						
WINDOW, NIGHT						
INFILTRATION	VOL, CU.FT.=	Q=VOL. X RATE	.0182Q =	$.0182Q \cdot \Delta T$ =	$.437Q\Delta T$ =	$.437Q \cdot DD$ =
TOTALS						

X 10^5BTU

SOLAR GAIN

WINDOW AREA X SHADE COEFF. X SOLAR FACTOR X 24 HR. X HEATING DAYS X Y % 1550 = X 10^5BTU

								X 10^5BTU

TOTAL X $10^5\frac{BTU}{YR}$

ANIMAL + UTILITY GAIN = NO. PEOPLE X 800$\frac{BTU}{HR}$ X 24 HR. X HEATING DAYS = X 10^5BTU

68

67

HEAT LOSS = ______ SOLAR GAIN = ________ ANIMAL + UTILITY GAIN = ____________

NET ANIMAL LOSS = ____________

---

*WINDOW $H_{DAY} = A/R_D \cdot 8HR \cdot \Delta T_{AVE}$; $H_{ANN} = A/R_D \cdot 8HR \cdot DD$

$H_{NIGHT} = A/R_N \cdot 16HR \cdot \Delta T_{AVE}$; $H_{ANN} = A/R_N \cdot 16HR \cdot DD$

HEAT GAIN

1) Measure the surface area of windows on all four sides of the house. Tabulate.

2) Assign a shade coefficient as follows: a totally unobstructed single pane window has a shade coefficient of 1.0; double pane 0.9; triple pane 0.8 etc. If a window is partially shaded by a tree, reduce this coefficient accordingly, i.e. a triple pane window receiving about one-half total radiation has a shade coefficient equaling 1/2 x 0.8, or 0.4.

3) Use the following table to compute winter solar heat gain factors, BTU/hr·ft^2

ORIENTATION	40	41	42	43	44	45	46	47	48
NORTH N	7.0	6.9	6.7	6.6	6.5	6.4	6.3	6.1	6.0
NORTHEAST	11.0	10.7	10.3	10.0	9.8	9.5	9.3	9.1	9.0
EAST E	29.0	28.5	28.0	27.5	27.0	26.5	26.0	25.5	25.0
SOUTHEAST	50.0	49.7	49.4	49.0	48.5	48.0	47.4	46.7	46.0
SOUTH S	62.0	62.1	62.0	61.8	61.6	61.1	60.6	59.9	59.0
SOUTHWEST	50.0	49.7	49.4	42.0	48.5	48.0	47.4	46.7	46.0
WEST W	29.0	28.5	28.0	27.5	27.0	26.5	26.0	25.5	25.0
NORTHWEST	11.0	10.7	10.3	10.0	9.8	9.5	9.3	9.1	9.0
HORIZONTAL	45.0	43.6	42.2	40.8	39.4	38.1	36.7	35.3	34.0

4) Assume 275 heating days for Brunswick, Maine (with 7500 Degree-Days). Make corrections for your locale.

5) The variable "Y" expresses a solar intensity factor based on elevation, percentage sunshine, pollution, and a number of other factors. If you live within 75 miles of the coast, enter 825 in this column. If you live further inland than 75 miles from the coast, enter 775.

ANIMAL AND UTILITY GAIN

Compute these additional gains due to the mere presence of physical bodies and the energy-consuming activities they engage in.

TOTALS

Compute the net annual loss in 10^5 BTU, or therms, the equivalent heating value of one gallon of oil, or 100 ft^3 of natural gas. At 50¢ per gallon of oil, we can quickly see how our energy dollars go up the chimney, not into the bank.

RADIATION

Radiation is an important but poorly understood form of heat exchange. Unlike heat transfer by conduction or convection, radiant exchange can occur in the absence of matter. The sun's energy travels by radiation through the void of space. Radiant energy travels at the speed of light, straight out in all directions from the central source.

A wood stove offers an excellent example of radiant heat exchange. About 70% of the heat transfer from a wood stove to a room is caused by radiant exchange. For this reason, every spot of a room to be heated should "see" the wood stove. Traveling in straight lines, radiant energy waves are stopped and converted to heat when they strike objects. Placing a piece of glass or insulative sheathing between you and a wood stove will block the radiation.

The effectiveness of radiant heat transfer is also dependent on the nature of a material's surface. Wood stoves are traditionally painted black because black metal surfaces have a greater ability to radiate heat. Relative to a perfect emitter -- a "black body" at the same temperature -- a wood stove can emit 90%-95% of the heat contained in its metal walls. On the other hand, a chrome-plated, highly polished stove would radiate only about 2%-4% of the stove's heat. Clearly, painting hot water radiators silver is not a good idea, since bright metallic surfaces are not as efficient emitters as black ones.

A practical example of this radiant heat effect occurs when a person decides to place the white side (as opposed to the silver, reflective side) of the Thermoply® panel of an insulating shutter facing outwards in order to avoid a "space age" metallic look from the outside. But, because the emissivity of the white surface is five times greater than the aluminum foil, the R-value of this shutter drops from 7.21 to 5.41. The price for this aesthetic change is R-1.8.

ENERGY AUDITS

Several companies within the state of Maine offer professional "energy audits". For a fee these groups will do a thorough thermal and structural analysis of a building. The resulting data is analyzed by computer program to determine which retrofit options are the most cost effective.

The state Office of Energy Resources will send energy audit forms for a self-inspection to any homeowner within the state. Typically, if most cost effective retrofit options are followed (i.e. those that payback within five years), then the heating bill for a house can be cut in half. The amount of the net savings will depend on how much of the actual work is done by the homeowner and how much is contracted out.

CHAPTER SIX

PASSIVE SOLAR

In solar design one precept is generally accepted: the simpler a system is, the better. Because of its inherent simplicity, passive solar design is gaining followers at an accelerated rate. The Second Annual Passive Solar Conference held in Philadelphia in March 1978 drew participants from 43 states and 26 countries. As one solar advocate put it, "The toothpaste is out of the tube." Passive solar design principles are beginning to gain worldwide acceptance.

The major research conclusion made at the Los Alamos Laboratories in New Mexico is that a well designed passive system using a vertical glass wall performs nearly as well as an active system tilted at near optimal angle. The trick lies in properly designing the system.

PASSIVE, HYBRID AND ACTIVE SYSTEMS

Within solar circles there are accepted definitions of each of these three generic types of systems. The distinction is made among the three by determining the percentage of non-renewable energy required in relation to the heat output of the system.

Any solar system that delivers 50 times more heat to the building than the amount of non-renewable energy it uses can be classified as "passive". For example, if a solar greenhouse were to be built on a remote island without access to electricity, gas, oil or any conventional (man-made) energy, then that structure would have to be purely passive, by definition. It would be powered solely by natural energy forces.

Hybrid systems like the Region #10 Vocational solar greenhouse use non-renewable energy (fossil fuel or nuclear-derived electricity) for blowers and lights. However, because the ratio of energy captured to non-renewable energy used is less than 50 but greater than 20, the system can be classified as "hybrid" solar.

Active solar, then, has an out-in ratio of less than 20. Whereas active systems generally use expensive, complex energy consuming equipment, passive systems rely on natural energy flows with a minimum of mechanical hardware. Free convection and radiation are the primary heat transfer mechanisms. The building is the collector, storer and distributor of the heat.

HOW PASSIVE SOLAR WORKS

Passive solar design attempts to achieve three results: 1) to increase the amount of solar radiation entering a structure; 2) to provide adequate materials for storage of heat; and 3) to reduce heat loss. In new house construction, passive solar design principles can be easily incorporated. Any house that is designed today without using some of these design principles begs for unnecessarily high fuel bills. Already constructed houses can be retrofitted (thermally upgraded) to maximize passive solar benefits. The cost effectiveness of each retrofit option varies greatly.

DESIGN PRINCIPLES

A general design process follows.

A. Determine the true energy demand. A conventionally heated home in Maine that runs out of oil can be said to be 100% solar heated. The inhabitants very well may not be comfortable, but they can probably survive. In other words, the first step of the design process is to determine what your true energy needs are. Can you tolerate setting the thermostat back at night to 60°F.? 55°F.? 50°F.? Will you be willing to conserve hot water by taking shorter showers? Washing dishes less often?

The percentage that solar (active or passive) can contribute to your energy demand will be determined to a large extent by your lifestyle. Without noticeable discomfort, most Americans could cut their energy consumption in half. Performing a detailed personal energy audit is the essential first step in determining the viability of solar heat.

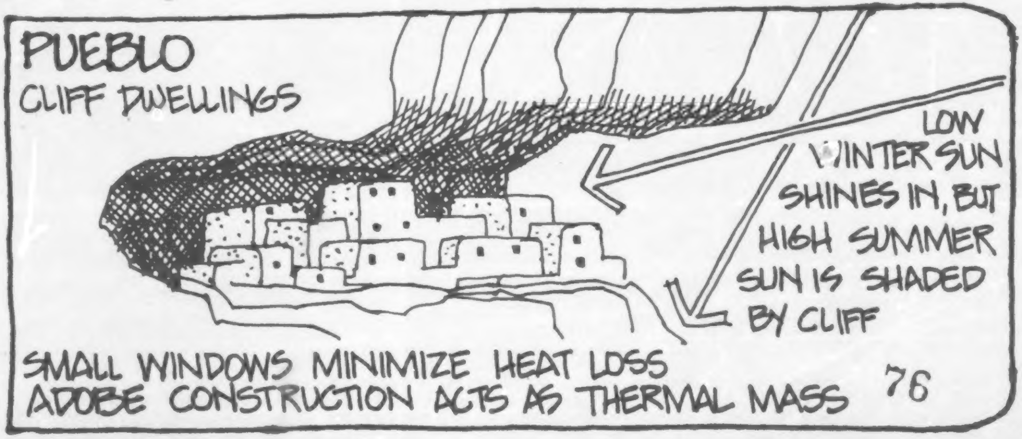
B. Site. Every attempt must be made to take advantage of energy flows at the particular house location. Houses should be sited to use trees effectively, and fences, nearby buildings and natural terrain to their fullest advantage. The Maine Audubon Society's solar building was sited so as to use a row of tall spruce trees for wind protection from the north. The building's low-sloping, saltbox roof helps to cushion the building against cold northern winter winds.

South-facing glass or glazing is essential for all effective solar designs. As the Los Alamos tests show, a vertical glass wall can be as efficient as a properly oriented, tilted, active collector. Because of winter snow ground cover here in Maine, a vertical wall will actually receive more insolation (i.e. solar radiation reflected off the snow) than would a comparable collector at 60° tilt. Therefore, conventional (vertical) windows can be effective solar collectors.

An important design principle, then, is to orient windows to the south. Between 30%-50% of the south walls should be glazed, depending on thermal mass and nighttime shuttering. Windows facing east or west have questionable heat gain properties.

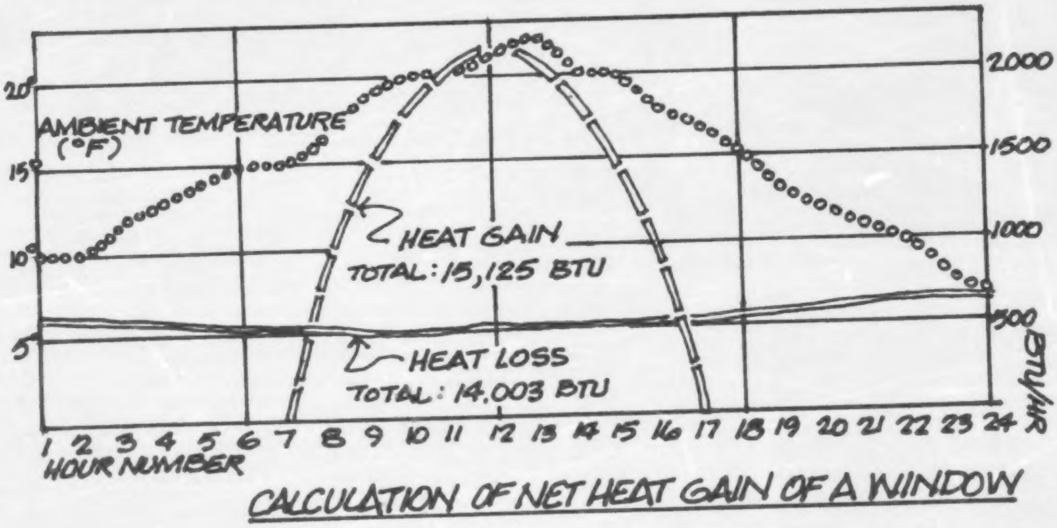
The question of aesthetics enters. Thermally speaking, the ideal house is one with no windows, or else an underground house. Common sense dictates these options as unworkable; humans are not moles. But a variety of options can be used that attempt to reconcile thermal efficiency and aesthetic considerations. The proper blend is an individual's choice.

C. Overhangs. The Southwest American Indians effectively used overhangs.


PUEBLO
CLIFF DWELLINGS
LOW WINTER SUN SHINES IN, BUT HIGH SUMMER SUN IS SHADED BY CLIFF
SMALL WINDOWS MINIMIZE HEAT LOSS
ADOBE CONSTRUCTION ACTS AS THERMAL MASS
76

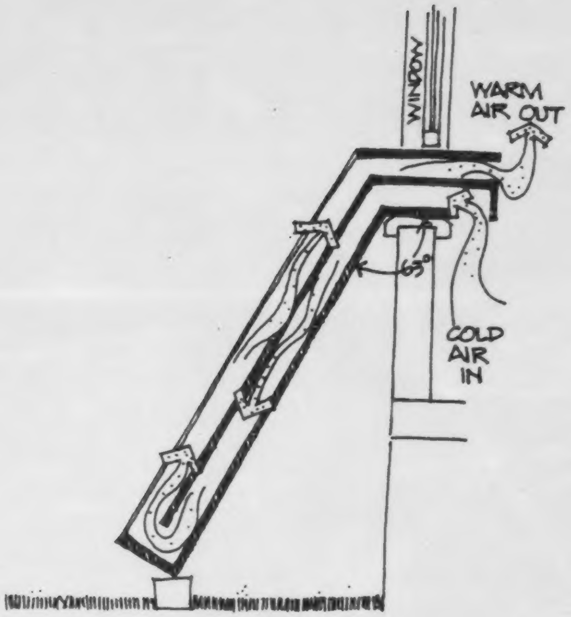
The object is to block out unwanted summer sun but to allow for maximum winter light. Today, people use awnings and trellises with green plants for existing houses, or properly engineered overhangs for new houses.

D. Shutters and Shades. In order to minimize heat loss, thermal shades and shutters can be used. These devices dramatically reduce heat loss in the winter, and they can also be used to reduce heat gain in the summer. South-facing windows can provide a substantial net energy gain if they are shuttered at night. The performance of a window during the course of a day verifies this statement.



CALCULATION OF NET HEAT GAIN OF A WINDOW

E. Window Collectors. As a solar retrofit, window collectors are receiving much attention. Those collectors which double as increased collector surface and glazing insulator are the most cost effective.



One goal of passive solar design is to increase south-facing glazed area. Because vertical collector surfaces are just as efficient as tilted ones in Maine during the winter, the south-facing window is a good bet. Covering these windows at night allows them to work effectively.

F. Framing Considerations. Design principle #3 of passive solar is to minimize heat loss. Many builders in Maine have gone from 2"x4" construction to 2"x6". This increased dimension stock enables the builder to place 6" of fiberglass insulation in the wall cavity rather than the standard 3½". Using larger framing members allows for a 24" on center construction, and therefore less total wood. Owens-Corning calculates a 30% reduction in total board feet of wood if 2"x6" construction is used.

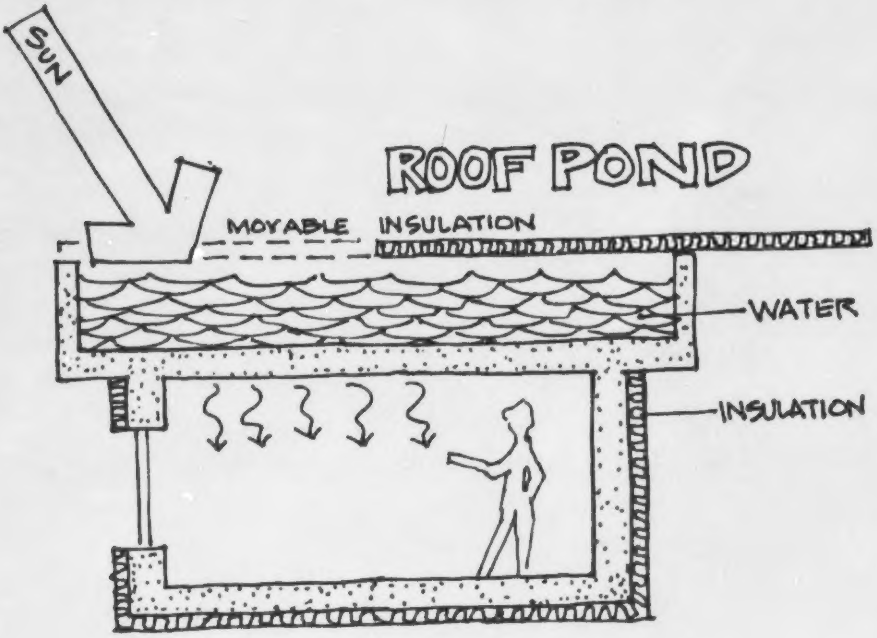
However, a very efficient wall can be achieved using 2"x4" construction with 1" exterior insulative sheathing. Proper care must be taken to avoid vapor buildup in the walls and potential dryrot of the sills.

G. Additional Thermal Mass. The addition of thermal mass helps to moderate interior temperatures. A thorough discussion of thermal mass appears in Chapter 9. Three general design principles are: 1) the structure should have the capability of storing about 60% of the incident solar radiation; 2) the sunlight should be diffused over the entire mass; and 3) thermal mass elements should be building elements.

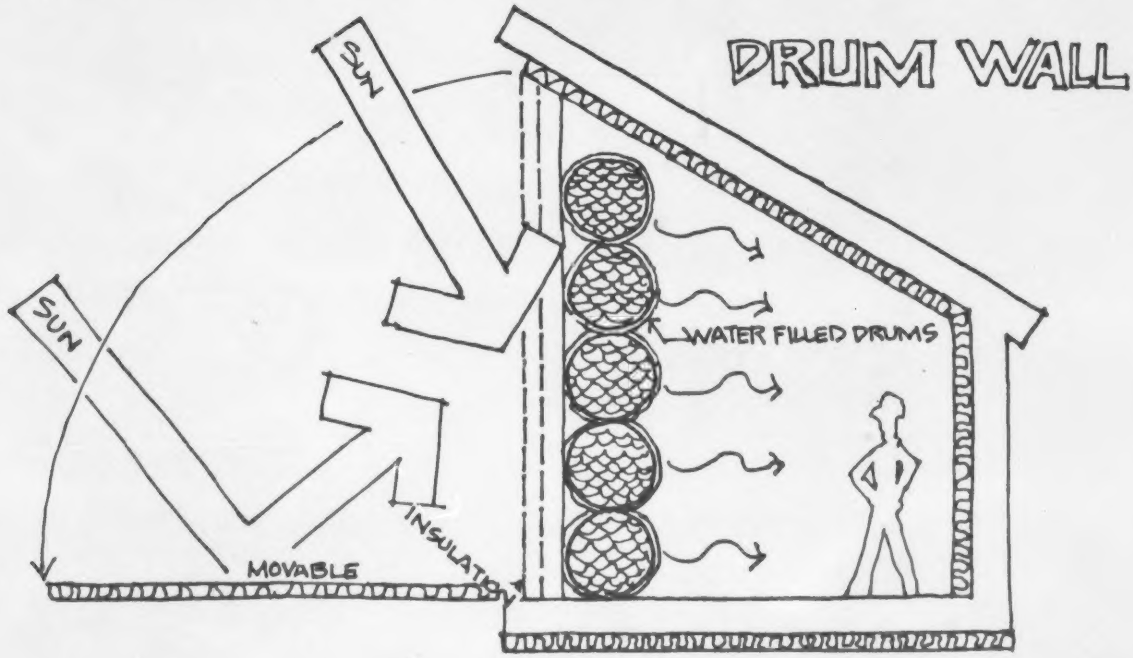
PASSIVE SOLAR SYSTEMS

The following three passive solar systems achieve the desired effects of 1) increasing the solar energy entering the building, 2) storing the heat, and 3) reducing the heat loss.

Case One: The Hay Roof Pond System. The roof consists of (from the bottom up) an uninsulated ceiling (usually metal supported by steel beams), a wall-to-wall layer of "water bed", and, finally, giant insulated motor-operated insulation panels. On a sunny day, the panels retract, exposing the water beds to the sun. At sunset, the panels close, preventing the upward heat loss from the heated water beds. Insulation on the underside is negligible, so the heat radiates downward into the living space. In the summer, the operation is reversed. Opening the panels at night allows the bags to cool by radiation to the cold night sky. During the day, the panels are closed and the bags absorb excessive living space heat.

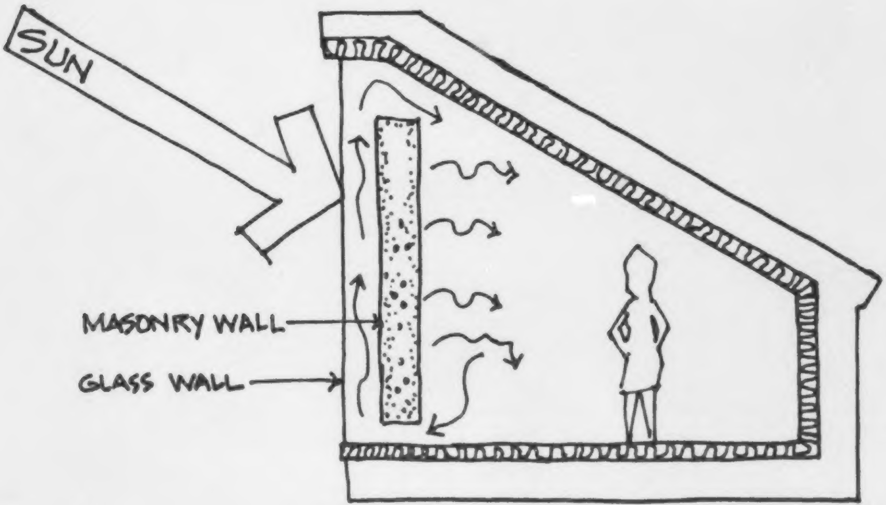

SUN
ROOF POND
MOVABLE INSULATION
WATER
INSULATION

Case Two: Drum Wall. An alternative system is the "drum wall". The designer, Steve Baer, erected a rack of water-filled 55-gallon drums in front of a glass south wall. During the day


DRUM WALL
SUN
SUN
WATER FILLED DRUMS
MOVABLE
INSULATION

the sun strikes the black ends of the drums and warms the contained water. At night, giant insulating shutters cover the windows, reducing heat loss.

Case Three: Trombe Wall. A more effective but less conventional technique is the Trombe Wall. It consists of a concrete wall about 12" thick, erected just behind large south-facing windows. The heat balance between the spaces in front and behind the concrete wall is controlled to some extent by controllable louvers at the base and top of the wall. Again, the windows are insulated at night. The drawback of the Trombe Wall is that it blocks the direct sunlight and view from the living space behind it.



TROMBE WALL

As opposed to masonry for thermal mass, water can be used. A variety of water walls have been designed and constructed to perform well. Because water is a more efficient form of thermal mass than masonry, a 30% reduction in exposed surface area can be used in direct gain water wall systems.

CHAPTER SEVEN

WINDOWS AS SOLAR COLLECTORS

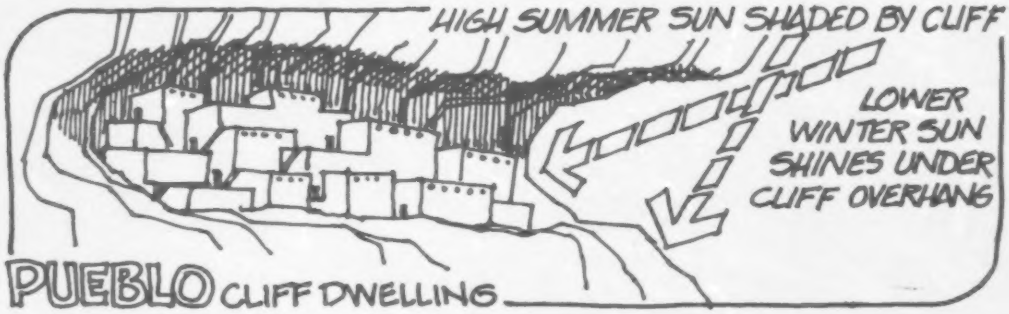
A flat plate solar collector is basically an auxiliary "window" for capturing solar energy. It is strategically placed to make the most of its collection capacity.

Windows, on the other hand, are often placed equally around the four sides of a house. The Farmers Home Administration (FmHA) requires that 10% of the floor surface area of a house be equaled in square feet of window. However, the code does not tell where those windows must be situated.

Any solar designer knows the importance of proper window orientation. Two hundred years ago, houses in New England were oriented to face the sun and to avoid the cold winter winds. Today's suburban residential layouts usually ignore solar orientation. Form has superseded function.

Traditionally, a window is asked to do two separate tasks: to let in light, and to provide ventilation. Yet the properties of light and air are quite different. We must re-think the function of windows and re-design our houses. Vents should be used to let in air. Insulating shades and shutters should be used at night to keep in heat. The imminent energy crisis will challenge us to re-think design basics.

For hundreds of years Southwest American Indians have been designing adobe structures with windows properly situated (i.e. placed high up on the walls to reduce radiation gain, and blocked to minimize ventilation during the hottest part of the day.)

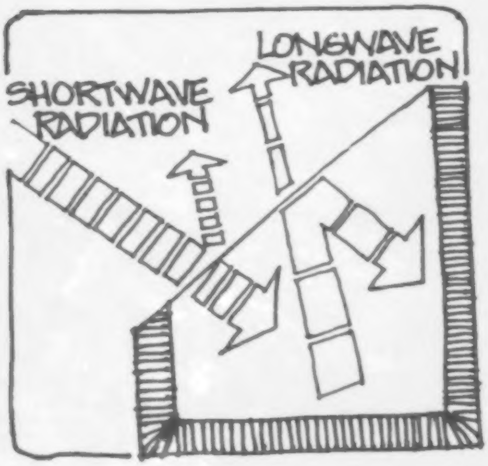

HIGH SUMMER SUN SHADED BY CLIFF
LOWER WINTER SUN SHINES UNDER CLIFF OVERHANG
PUEBLO CLIFF DWELLING

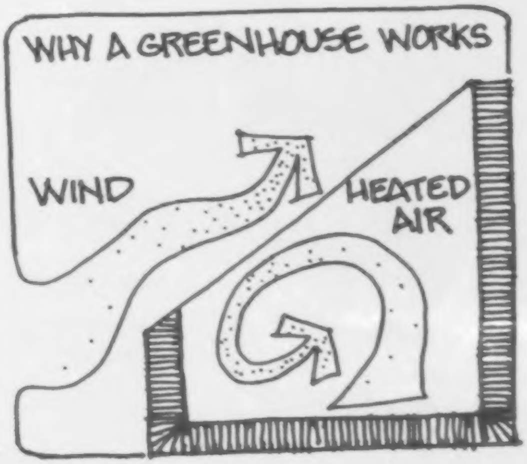
At the 1933 Chicago World's Fair, the architectural team of George and William Keck designed one of the first "solar" houses with a preponderance of south-facing glass. Their design evolved into well-engineered solar structures with proper overhangs and optimal southern glazing. The advent of the cheap alternative fuels -- natural gas and oil -- temporarily halted the demand for their solar houses, however.

THE GREENHOUSE EFFECT

Windows make efficient solar collectors because of the greenhouse effect. This term is used to explain why heat builds up inside a translucent or transparent enclosure on a sunny day. The common explanation is that the greenhouse glass or glazing (sometimes translucent fiberglass) allows much of high-energy, visible light and ultraviolet radiation to enter the enclosure. Once this electromagnetic radiation strikes objects within the greenhouse, it is transformed into lower-energy, longer wavelength heat, or infrared radiation. It is traditionally believed that the glass or glazing material is opaque to this infrared or heat energy. Thus high-energy photons enter the greenhouse, are transformed to long-wave radiation, and are trapped within the structure. This process is conventionally defined as the "greenhouse effect".

In fact, most greenhouse glazings are fairly good transmitters of infrared radiation. The primary reason a greenhouse builds up high temperatures relative to the outdoors is because the heat energy emitted from sun-touched objects is not allowed to blow or convect away. The convection (transfer of heat by a moving fluid) losses are kept to a minimum.

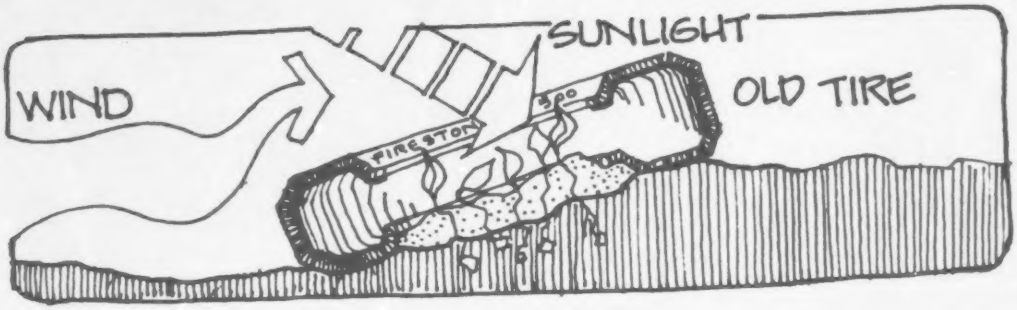




Greenhouse glazing also provides effective thermal barriers by providing surfaces to which films of dead air can cling. Fiberglass insulation in a house wall works by trapping pockets of dead air. Similarly, a double layer of glass, fiberglass or plastic creates a layer of stagnant air which insulates against conduction heat loss.

Scientists have built greenhouses side by side, identical in all respects save that one used glass for its glazing and the other used rock salt. The rock salt does not discriminate between ultraviolet and other forms of electromagnetic radiation. If the greenhouse effect had worked as it is conventionally thought to, the glass greenhouse should have built up a much higher inside temperature, its glass covering being more opaque to the infrared radiation than to visible light. But, in fact, both greenhouses achieved nearly identical temperatures. It is, therefore, not the opaqueness of the glass covering that is the primary cause of the "greenhouse effect". The greenhouse gets warm simply because the heat is not blown away.

An excellent practical application of this true "greenhouse effect" is provided by Mr. Earl Blackstone of Brunswick, Maine, who uses discarded automobile tires as solar greenhouses. These black forms, when placed on top of a mulch pile and filled with several shovelfuls of sand, create the true "greenhouse effect" despite the absence of an overhead covering. The black enclosure heats up and warms the air inside it which is kept from flowing away. Thus these tires become excellent seedling starters -- mini solar greenhouses of the recycled variety.



THE EARTH'S ATMOSPHERE

The earth's atmosphere acts as a thermal blanket, keeping its surface an average of about 33°C. warmer than it would be without it. The primary elements making up this blanket are CO_2, water vapor and clouds. Each absorbs infrared radiation of different bands in different quantities. The CO_2 and water vapor act somewhat like the glass of a greenhouse in that they are relatively transparent to visible radiation but more opaque to infrared. The atmosphere absorbs the infrared radiation given off by the earth's surface, and then re-radiates this heat back to the earth and out to space. Clear nights are colder than cloudy nights because there is less of a thermal blanket to prevent the heat from leaving the earth's surface.

In short, then, the "greenhouse effect" is misunderstood; the glass covering of a greenhouse works because it reduces convection losses, not because it transmits heat in any special way.

MAINE APPLICATIONS

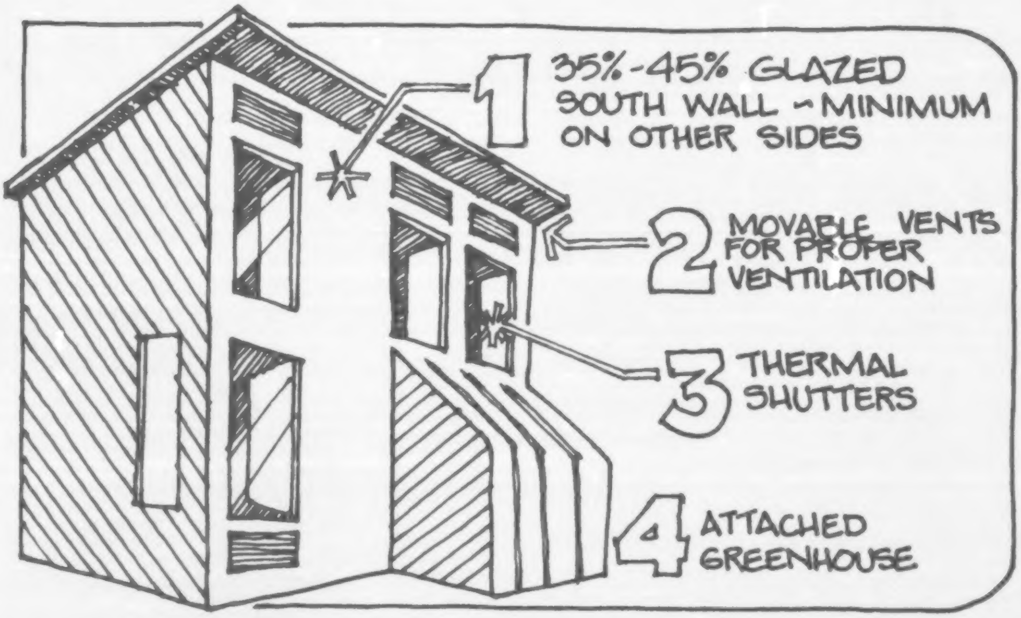
In Maine there is a growing movement towards passive solar house design. Cornerstones, the Wing School of Shelter Technology in Brunswick, has instructed more than 1000 potential owner/builders. They are strong advocates of optimizing the energy gain available through the proper use of glass. Four techniques are widely used:

1) Make the south wall of the structure 30%-50% glass and minimize glazing on other sides of the structure.

2) Use vents for proper control of air exchange; do not use the "window" to let in both light and air.

3) Reduce nighttime heat loss through windows by using thermal shutters or shades.

4) Add an attached solar greenhouse to help provide supplemental heat to the house.


1 35%-45% GLAZED SOUTH WALL - MINIMUM ON OTHER SIDES
2 MOVABLE VENTS FOR PROPER VENTILATION
3 THERMAL SHUTTERS
4 ATTACHED GREENHOUSE

Techniques #3 and #4 deserve much consideration.

INSULATING SHUTTERS

Because a single pane of glass has an R-value (or thermal resistance) of only 1.0, it loses a tremendous amount of heat. Compared to an insulated 2"x4" wall, such a window loses about ten times as much heat per unit of surface area. However, during the daytime, a properly situated window allows sunlight (light means heat) into the building.

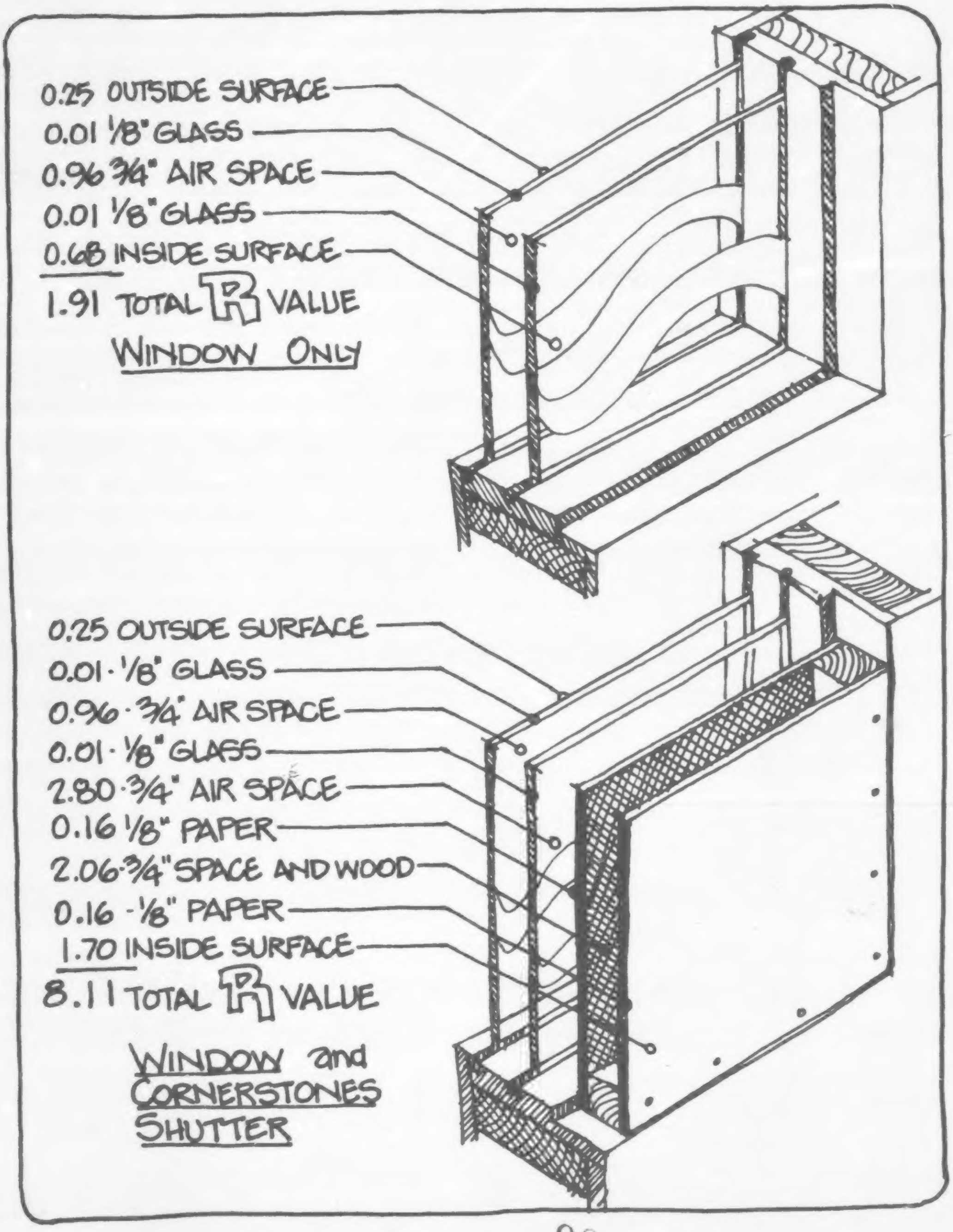
It has been estimated by the Department of Energy that:

> "One-fourth of the energy used in the United States each year to heat and cool residential and commercial buildings is wasted because of unwanted heat gains and losses through windows. This energy loss amounts to about 5% of the total U.S. energy consumption and is equivalent to 1.7 million barrels of oil per day. Heat loss and gain through windows represents a significant burden for the consumer."

In Maine about $1.00 is added to fuel bills each year for every square foot of single-paned window area.

Once the function of a window is re-thought, it makes sense to install thermal shutters or shades. The student project section of the curriculum explains in detail how to construct thermal shutters -- a very cost effective "solar" retrofit.

The following illustration shows why a double-paned window with thermal shutters is four times more energy efficient than a single-paned window. Just as shutters were once used to keep out street dirt, noise, rain, hail and vagabonds, interior thermal shutters can be used to keep the oil dealer away. The addition of colorful fabrics or wallpapers can make these shutters pleasing to the eye. Good aesthetics and function can go hand in hand.


0.25 OUTSIDE SURFACE
0.01 1/8" GLASS
0.96 3/4" AIR SPACE
0.01 1/8" GLASS
0.68 INSIDE SURFACE
1.91 TOTAL R VALUE
WINDOW ONLY
0.25 OUTSIDE SURFACE
0.01 · 1/8" GLASS
0.96 · 3/4" AIR SPACE
0.01 · 1/8" GLASS
2.80 · 3/4" AIR SPACE
0.16 1/8" PAPER
2.06 · 3/4" SPACE AND WOOD
0.16 · 1/8" PAPER
1.70 INSIDE SURFACE
8.11 TOTAL R VALUE
WINDOW and CORNERSTONES SHUTTER

WINDOW BOXES AND ATTACHED SOLAR GREENHOUSES

In popular literature there have recently occurred numerous examples of window box collectors. (I.e. Popular Science, December 1978) In general, the function of the window collector is to extend the number of square feet of southern glazing. In all cases the economics of this retrofit option should be analyzed.

If we can capture 1200 BTU per square foot of collector per day during the heating season, and if a window box collector measures 3' x 5', over the course of a heating season, at a maximum we can collect:

$$15\ ft^2 \times 1200\ BTU/ft^2\text{-day} \times 275\ days = 4,950,000\ BTU$$

(per heating season)

At 50¢/100,000 BTU for oil, that translates to $24.75 worth of oil saved. We are assuming 100% collection of the energy striking the window collector. If our efficiency of collection is only 70% then our savings is a little more than $17.00. If the collector is made from inexpensive or recycled materials, then perhaps a window box collector is a good investment. It is also important that the installation be tightly sealed to avoid any extra infiltration losses through window cracks. We also assume that the window box collector will not be tampered with or vandalized.

ATTACHED SOLAR GREENHOUSES

Because of the dramatic increase in food prices and the dubious use of chemicals in growing and producing foods, many people are once again attempting to raise more and more of their own food. An attached solar greenhouse can provide two valuable functions: 1) it can add extra heat to the existing structure because of the increased area of south-facing glazing, and 2) it can provide a year-round growing environment. The details of attached solar greenhouses are discussed in Chapter 10 of this text.

CHAPTER EIGHT

THERMAL MASS

Those of us in Maine who live near the ocean experience the effect of thermal mass. During the winter the large mass of ocean water at around 35°F. helps to moderate seasonal temperature changes. The average January temperature for Portland is 23°F., whereas 50 miles inland at the same latitude, in Rumford, the average January temperature is 19°F. It is the high thermal capacity of water which makes it an excellent candidate for thermal mass storage in a solar system.

Structures designed for high solar gain require high thermal mass. During the winter on a sunny day, conventional greenhouses must be vented to discharge the buildup of unwanted warm air. In March and April conventional greenhouses are often covered with shading materials to reflect incoming solar energy and to prevent high inside temperatures. Thermal mass can reduce these fluctuations in inside temperatures, creating year-round environments suitable for plant growth.

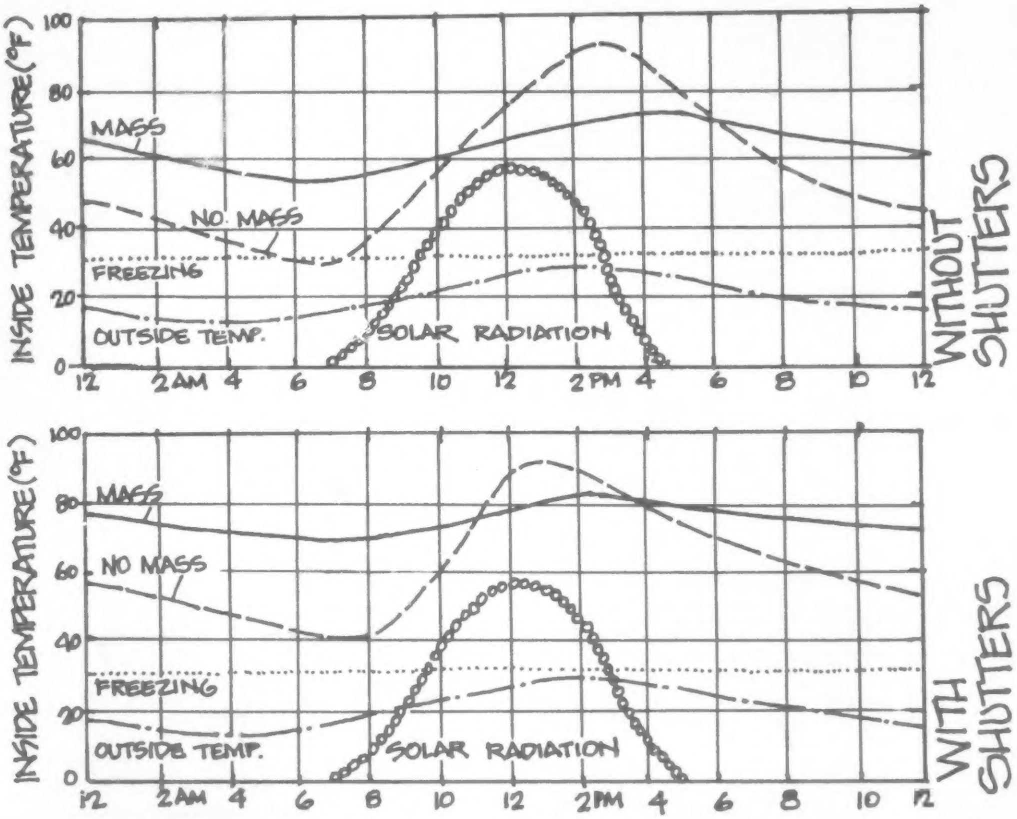
Technically, all matter possesses the ability to store heat. Some substances are just better than others. Any conventional structure possesses a thermal mass that is an attribute of the materials used in building the structure: the glass, wood, metal, furniture, and all other interior materials. Generally speaking, most structures do not possess enough thermal mass, however, to act as their own effective "solar batteries".

Thermal mass is added to a structure for two primary reasons:

1. To reduce the fluctuations in temperature caused by daily changes, for example, intermittent sunlight, day/night or point source heating; or, for example, by having a wood stove in a confined area.

2. To store the excess heat generated by efficient solar collection or some other heat source for use at a later time. When thermal mass is used for this purpose, it must be insulated and isolated from the interior, unlike thermal mass which is used inside a structure to temper daily fluctuations.

The following graph depicts the conditions inside the Vocational Region #10 solar greenhouse both with and without the addition of water as thermal mass.



PERFORMANCE OF REGION #10 GREENHOUSE

CLEAR DAY - JANUARY - 44°N LATITUDE

Alone, the greenhouse has a thermal mass of 3000 BTU per F.°. With the addition of 16,000 lbs. of water, the thermal mass of the structure increases to 19,000 BTU per F.°. The effect of this addition is to decrease the rate of temperature increase on a sunny day from 14F.° per hour to 2F.° per hour. The thermal mass also helps to slow the rate of cooling at night. In general, plants in a greenhouse cannot tolerate the thermal shock caused by extremely high and low temperatures. The addition of thermal mass is essential for tempering inside conditions in solar structures.

All substances have the ability to store heat, yet some are much more efficient than others. The two primary variables which determine our choice of thermal mass materials are specific heat and density.

Specific heat is defined as the amount of heat it takes to raise the temperature of one pound of a particular substance 1F.°. Some specific heats are:

Material	Specific Heat (BTU/lb.F.°)	Density (lb./ft.^{3})	Heat Capacity (BTU/cu. ft.F.°)
adobe	0.22	90	20
air	0.018	--	--
brick	.20	120	24
concrete	.23	150	34.5
steel	.12	490	59
stone	.21	165	34.6
water	1.0	62.5	62.5
wood	.33	32	10.6

The density of a material is the mass of the substance per unit volume. The more dense a substance is, the more useful thermal mass it offers because of its compactness. These two variables work together to determine heat capacity, the quantity we are trying to maximize. The formula Q = cm (where Q = heat content in BTU, c = specific heat, or BTU/lb.F.°, and m = mass in pounds) is the one that helps us choose the proper thermal mass material.

Other factors determining which materials to choose are cost and availability (the Maine Audubon Society used 3/4"-1½" washed river rock because it was locally available and cost nothing), toxicity and inertness (the use of water necessitates corrosion-resistant containers and anti-freeze safeguards), and the ability to allow heat in and out of storage (a large surface area is needed).

In general, the choice for thermal mass storage has been between rock or masonry and water. On a volume basis, water is two times more efficient than masonry; on a weight basis, it is five times more efficient. Water is also very inexpensive, non-flammable and non-toxic. Water has a higher sensible heat capacity than any other substance on earth.

LATENT HEAT STORAGE

Another type of storage involves the use of latent or phase change heats. The most common example is that of water when it freezes. As water freezes, it liberates 144 BTU/lb.

at 32°F. The sensible heat storage capacity of water is only 1 BTU/lb. per F.°. It is this phase change principle on which a refrigerator works. In a refrigerator, gases are vaporized, removing massive amounts of heat from the inside. Heat pumps and phase change solar hot water heaters are currently being used in a number of solar systems.

Glaubers salts ($NaSO_4 \cdot 10H_2O$) and other eutectic salts have been given much attention in the press. These chemical substances absorb and release much heat as they undergo hydration at a particular temperature. MIT uses eutectic tiles for ceiling storage in its Solar House #5 in the Boston area. Until technical problems are overcome, however, and such ceiling tiles become commercially available, the use of eutectic salt storage will have little practical application.

SIZING THERMAL STORAGE

General rules of thumb have been developed for sizing sensible (non-latent heat) thermal mass storage. For rock storage, the rule of thumb is 2-3 cu. ft. of gravel per sq. ft. of south window. For water storage, the rule of thumb is 3-5 gallons per sq. ft. of south window.

Several interesting methods for storing water have been devised. Sono-buoy cases are gray, polyethylene, 5½-gallon, recycled plastic containers that can be stacked vertically or horizontally once their caps are sealed. The water does not corrode the plastic. The walls of the container are thin allowing for excellent heat transfer. The surface area-to-volume ratio is high. The filled container weighs only 42 pounds. In all design respects these recycled military surplus containers make excellent water storage containers. They are available from the Brunswick Naval Air Station for 25¢ each, which is approximately 1/5 the cost of conventional storage containers. Other water systems have used five-gallon tins, 55-gallon drums, and one-gallon plastic milk containers.

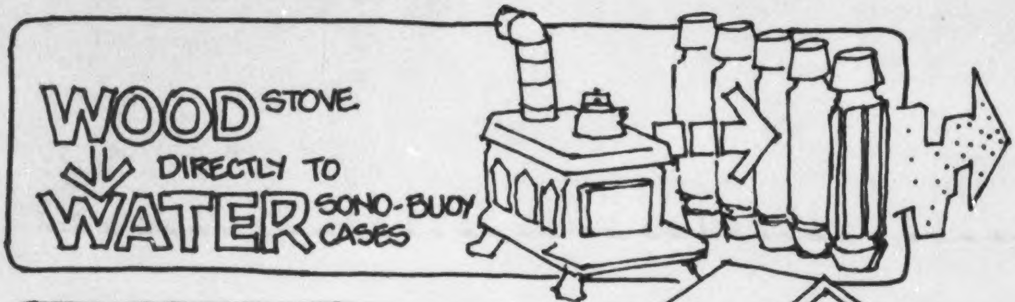
For rock storage several important design principles are now recognized:

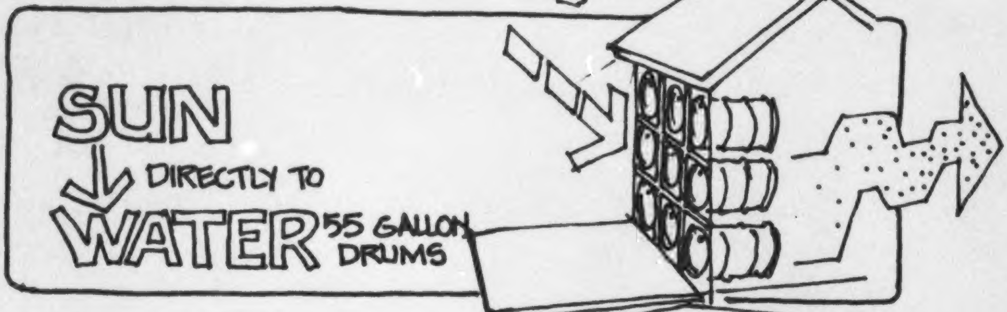
1) Locate the thermal mass in the center of the building so that unexpected heat loss will benefit the entire space.

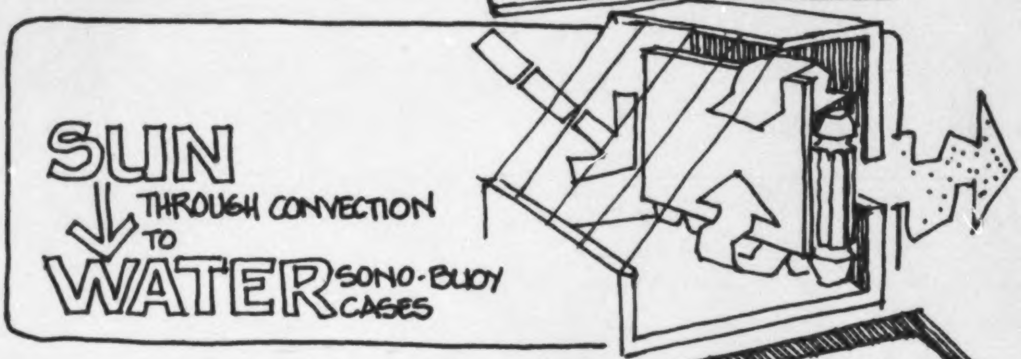
2) Avoid thermal stratification by layering rocks or by inducing circulation that allows for a proper heat exchange.

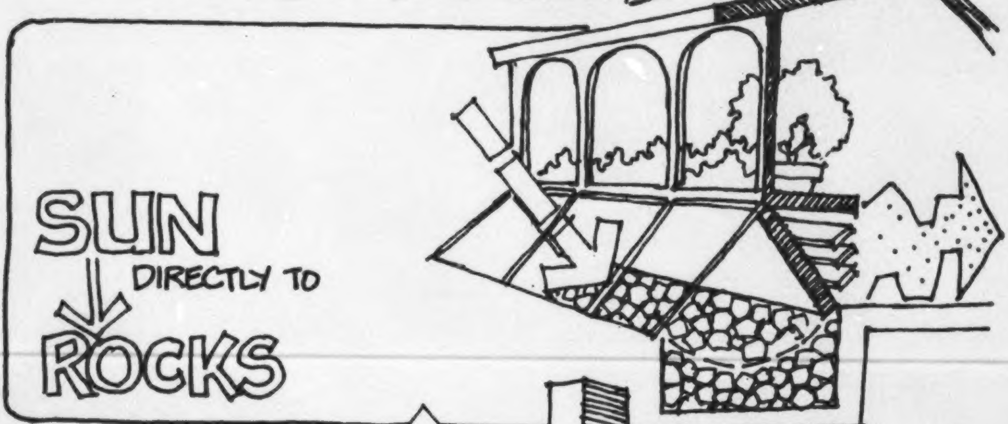
3) Do not finalize the volume of a thermal mass system until it has been operated to test its response time. An oversized system can have the effect of drawing off the comfortable warm air desired for the interior space.

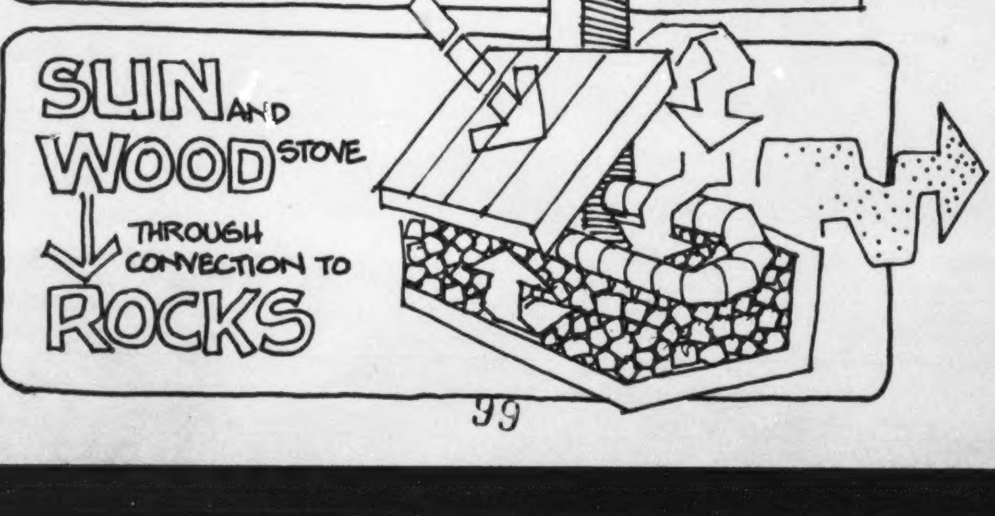
The drawing on the next page demonstrates how thermal mass can be incorporated into a variety of alternate energy systems.


WOOD STOVE
DIRECTLY TO
WATER SONO-BUOY CASES


SUN
DIRECTLY TO
WATER 55 GALLON DRUMS


SUN
THROUGH CONVECTION TO
WATER SONO-BUOY CASES


SUN
DIRECTLY TO
ROCKS


SUN AND
WOOD STOVE
THROUGH CONVECTION TO
ROCKS

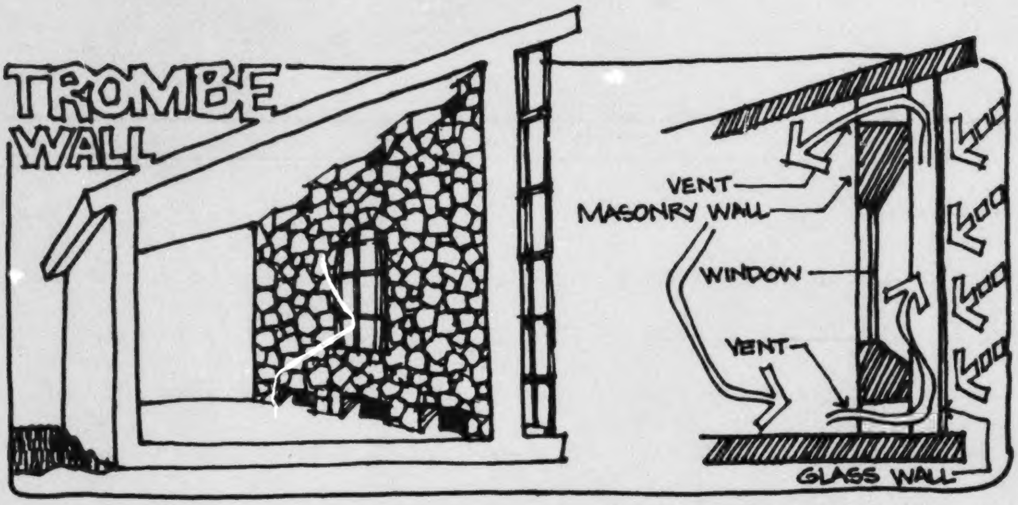
CHAPTER NINE

MASS WALLS

Like most "solar innovations" mass walls have been around for some time. There is record of a direct gain mass wall system which was constructed in 1881 in Salem, Massachusetts. In the 1950's Felix Trombe (pronounced like "bomb") built several direct gain mass wall structures near Odeillo, France. The name "Trombe wall" has become synonymous with mass wall passive solar systems.

The basic idea of a solar mass wall is simple: a wall of great mass absorbs the solar energy which strikes it after the incoming rays have passed through a glazed surface. At night the mass wall transfers its heat to the interior space. It is this thermal time lag property of adobe that has helped to heat the houses of Southwest American Indians.

Instead of allowing sunlight to stream in through southern windows to strike a slab on the floor or water containers on the back wall, a mass wall system places its thermal mass directly inside the glazing. The air between the glazing and the mass wall heats up and passes through the higher air vents into the interior space. At night the mass radiates heat to the room. Both convection and radiation heat transfer are at work.



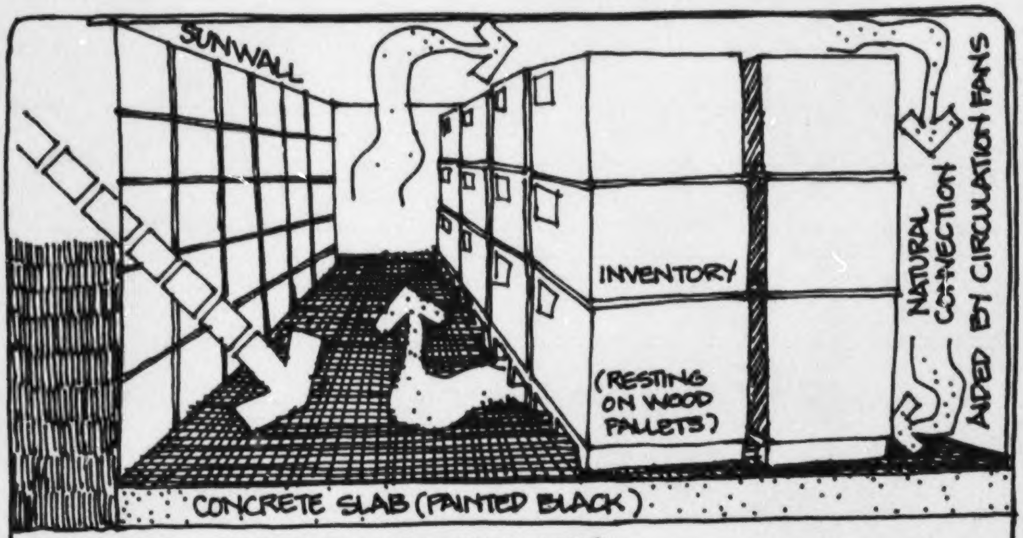
From the inside, the south wall may look like any other solid wall except for window openings or air vents. Mass walls can be designed also to block off selected portions of a southern view.

Mass walls can be categorized in several ways: integral versus free-standing walls and masonry versus water walls. In any case the basic principles are the same.

Integral systems use the mass wall as a structural member of the building envelope. The mass wall carries the weight of the roof and is formed to the east and west walls. A building which places an outside glazing over an existing southern masonry wall exemplifies an integral mass wall system.

Free-standing mass wall systems, on the other hand, do not require that the thermal mass help support the entire structure. A classic example of a free-standing mass system is the Kalwall Corporation's warehouse building in Manchester, New Hampshire. Kalwall mounted 1750 square feet of Sunwall ® Solar window panel on the south side of a 20-year old warehouse.

An 8" thick black slab absorbs some of the direct radiation. In addition, the warehouse's inventory is placed 3½' from the glazing so that it, too, can absorb the sun's energy. In this case, the mass wall is the furniture in cartons, standing free of the building walls. Fans blow warm air throughout the stacks of boxes to help them absorb excess heat.


SUNWALL
INVENTORY
(RESTING ON WOOD PALLETS)
NATURAL CONNECTION AIDED BY CIRCULATION FANS
CONCRETE SLAB (PAINTED BLACK)

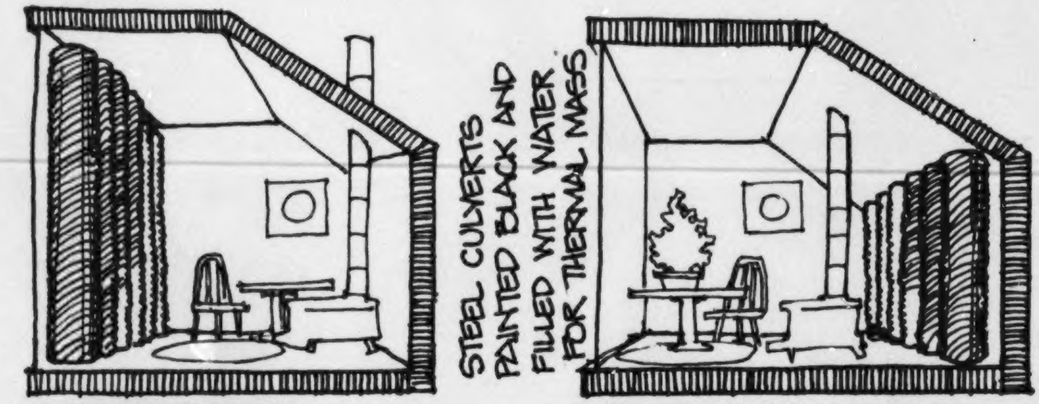
PASSIVE SOLAR WAREHOUSE

The system supplies 55% of the building's heating requirements, resulting in a yearly savings of 270 million BTU. The $8000 retrofit mass wall system will pay for itself over the course of seven years, assuming the price of oil stays at 45¢ per gallon. The higher the price of oil, the shorter the payback period.

In both integral and free-standing mass wall systems a major concern has been how to find inexpensive yet effective ways of preventing reverse thermosyphoning, i.e. the nighttime reverse cycling of warm air from the top of the room through the air vents, down along the cold glass and back into the room at floor level. Ingenious devices have been designed to alleviate this problem. A simple flap of drycleaner's plastic over the metal grid prevents this reverse flow.

MASONRY WALL VERSUS WATER WALL

The chapter on thermal mass points out that water has the highest heat capacity of any substance on earth. Water is therefore an ideal substance to use in a mass wall. The major problem with water has been finding suitable containers for large amounts of water. Steve Baer's 55-gallon "drum wall" is one solution. Another solution is to use more convenient sono-buoy cases of 5½-gallon capacity. They stack easily and offer excellent surface area-to-volume ratios. Large vertical culverts have also been used as well as fiberglass cylinders which double as containers for growing algae and raising fish.

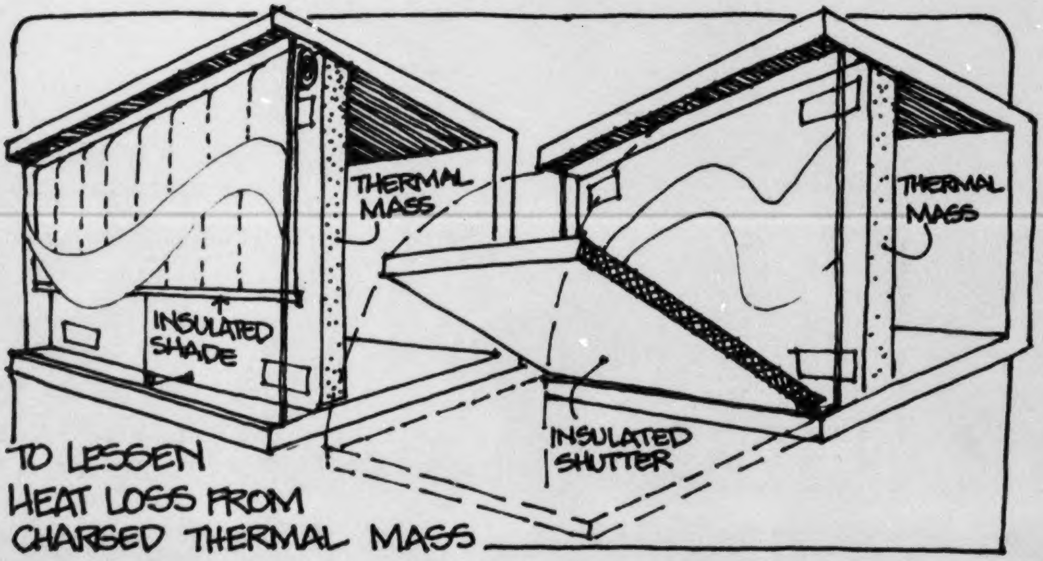

STEEL CULVERTS PAINTED BLACK AND FILLED WITH WATER FOR THERMAL MASS

PLACED IN FRONT TO MAXIMIZE DIRECT HEAT GAIN & FILTER SUNLIGHT

PLACED IN BACK TO ADMIT MORE SUNLIGHT IN ROOM, COMPROMISING HEAT GAIN

Concrete block walls with their holes lined with plastic have also been attempted. This last system combines water and masonry for heat storage. However, the thermal effect is close to that of a masonry wall alone.

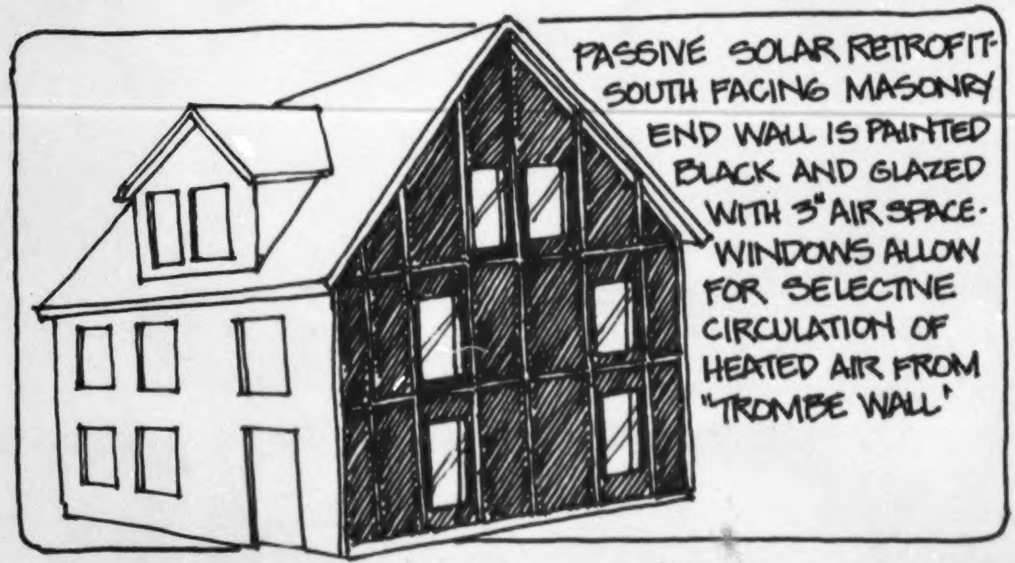
As with water walls, masonry can be used in a variety of ways. Blocks, bricks, veneered blocks, poured cement walls, adobe and stone all exhibit similar thermal characteristics when used in a direct mass wall. A major concern with any type of mass wall is the use of a thermal cover for the glazing. An exterior shutter, a bead wall, or an interior curtain between the wall and the glazing can be used. This thermal barrier helps to retard the nighttime heat loss from the charged mass wall through the glazing. Cost, aesthetics and the degree of automation desired all determine the viability of such systems.


THERMAL MASS
INSULATED SHADE
THERMAL MASS
INSULATED SHUTTER
TO LESSEN HEAT LOSS FROM CHARGED THERMAL MASS

TROMBE WALL RETROFIT

Direct gain mass wall systems are not limited to new houses. There are numerous retrofit options for residential structures as wall as for brick or concrete warehouses.

One interesting retrofit was done by the Northwest New Jersey Community Action Program (NORWESCAP) in Bloomsburg, New Jersey. A thin slurry of mortar mix and black masonry pigment was painted onto the rough textured plaster surface of the south-facing end wall. The perimeter of the collector was framed out in 2"x4"s in order to provide a 3" air space. Three 6"x12" vent holes duct the warm air from the 432 sq. ft. of collectors. To maintain the thermal mass of the existing south masonry wall, the designers chose to leave the insulation and sheetrock in place. The entire collector was covered with .025" thick Kalwall Sunlite fiberglass glazing. (The designers recommend using the thicker .040" Kalwall Premium glazing and also the use of a second glazing.) The total cost of the project amounted to 88¢ per square foot.

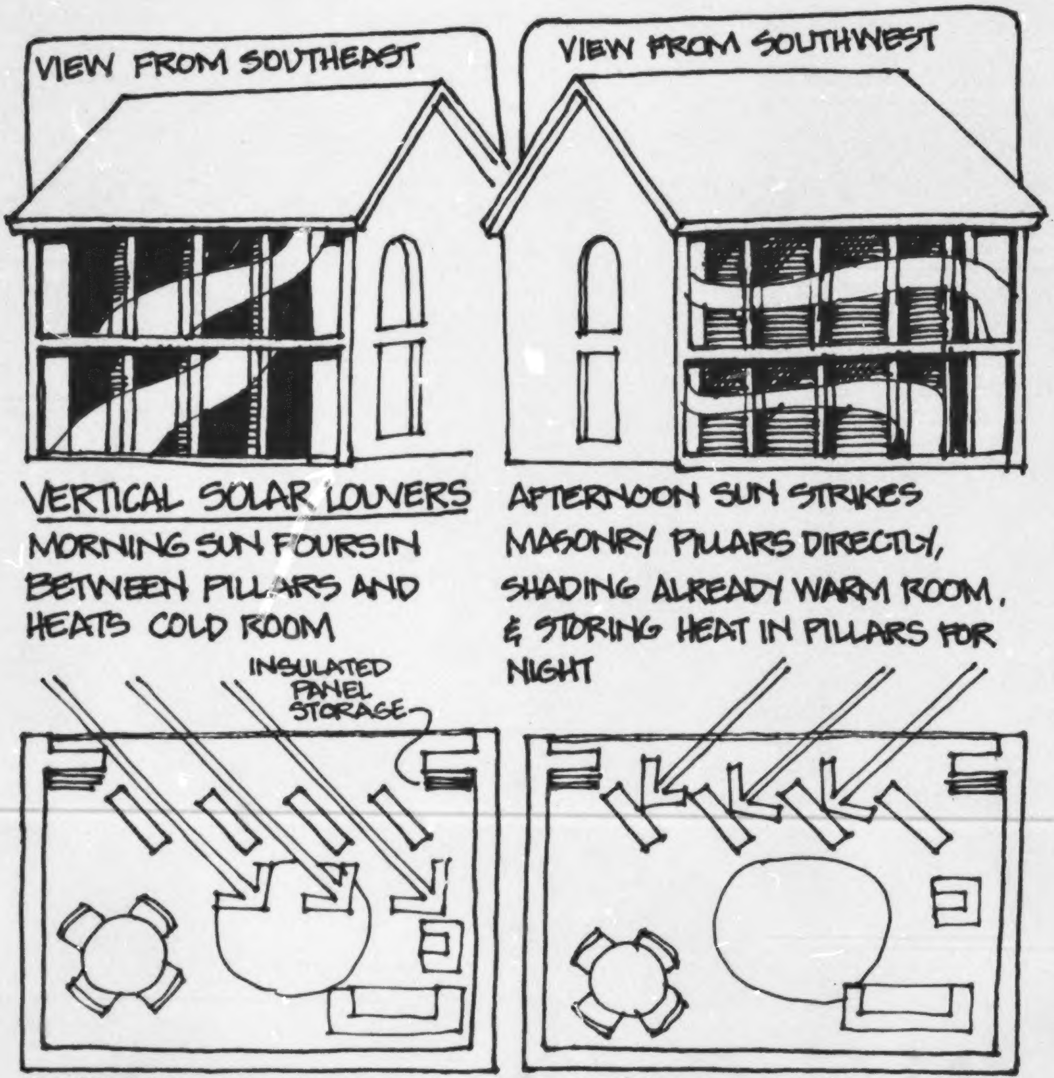

PASSIVE SOLAR RETROFIT-
SOUTH FACING MASONRY
END WALL IS PAINTED
BLACK AND GLAZED
WITH 3" AIR SPACE-
WINDOWS ALLOW
FOR SELECTIVE
CIRCULATION OF
HEATED AIR FROM
"TROMBE WALL"

The Kalwall Corporation has installed another interesting mass wall system: the retrofit of a vintage-1920 commercial brick building in Manchester, New Hampshire. In this case, the existing brick wall became the thermal mass. The windows were used as intake and exhaust ports to help establish proper air circulation. The wall retrofit produced temperatures as high as 153°F. with no harmful effects on the masonry. The net gain attributed to the wall is about 2.2 million BTU per day, or a savings of about 25.7 gallons of fuel oil per day. The wall works to add extra heat and also to insulate the building from further heat loss.

FUTURE DESIGNS

Trombe walls or direct gain mass walls appear to be cost-effective passive solar applications. A host of design rules is currently being generated. The idea is a simple one, yet the exact thermodynamic interactions are still poorly understood. Is it better to let the wall heat up and radiate to the interior spaces, or should precise air flow control be maintained? How well do water and masonry work in conjunction with each other? Can mass walls be made attractive enough so that the general public will accept them?

These and many other questions await answers. Nevertheless, mass wall passive solar systems appear to be a wise investment. An integrated mass wall/greenhouse/direct gain system may provide the ultimate answer. The ancient mass wall solar concept will once again have its day.


VIEW FROM SOUTHEAST
VIEW FROM SOUTHWEST
VERTICAL SOLAR LOUVERS
MORNING SUN POURS IN BETWEEN PILLARS AND HEATS COLD ROOM
AFTERNOON SUN STRIKES MASONRY PILLARS DIRECTLY, SHADING ALREADY WARM ROOM, & STORING HEAT IN PILLARS FOR NIGHT
INSULATED PANEL STORAGE

ADVANTAGES OVER TROMBE WALL: MORE EVEN HEAT, YOU CAN SEE OUT THE WINDOW, AND CLEAN IT AND INSULATE IT EASIER AT NIGHT.

CHAPTER TEN

SOLAR GREENHOUSES

Attached solar greenhouses are becoming an increasingly popular retrofit option. They offer three major benefits: 1) an inexpensive, attractive living space, 2) a place for growing plants, and 3) a heat collector. The design of the greenhouse is determined to a certain extent by the primary end use. For example, the geometry of a heat-producing greenhouse is different from one designed specifically to raise orchids.

All greenhouses are "solar" in nature, in that they use the sun's energy to support photosynthesis. In this chapter, the solar greenhouses we consider are attached to or added onto an existing house. But a solar greenhouse can be free-standing just as well, in which case the north wall of the structure is solid (i.e. well insulated and wind proof). Solar greenhouses differ from conventional greenhouses in three major ways. They attempt to capture as much solar energy as possible; they use a variety of means to conserve energy; and they use thermal mass to moderate temperature swings.

The most compelling reason for constructing solar greenhouses in the Northeast is the cost of heat. Commercial greenhouses in Maine cost about $1.25 per square foot per year to heat. As fuel prices go up, commercial greenhouses go out of business. In bygone days when fuel costs were extremely low, commercial growers could rely on heat escaping through the loose glass panels to melt off the snow. For this reason the greenhouse superstructure did not have to be extremely strong since it had only the glass to support. A well-insulated attached solar greenhouse must be designed differently.

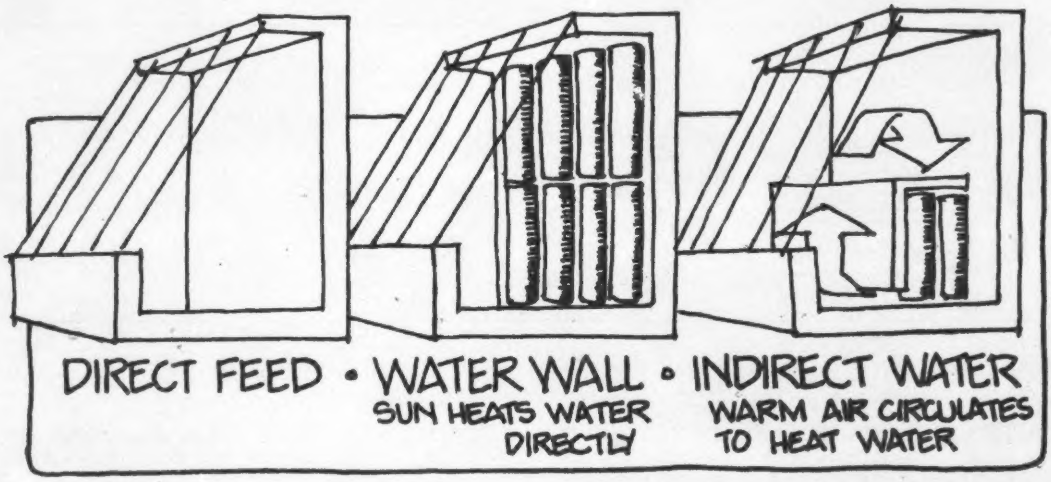
Commercial greenhouses overheat throughout the year, necessitating shading of the glass during spring, summer and fall. In addition, many conventional greenhouses are oriented without regard to the sun, even though the east/west orientation could achieve a 15% greater sun collection. In designing a solar greenhouse, specific considerations like orientation and solar obstructions cannot be overlooked. The greenhouse design principles at the end of this chapter outline some of these considerations.

GREENHOUSES AS SOUTHERN GLAZING

The major reason why attached solar greenhouses work is that double glazed south-facing windows on any structure offer a net heat gain. The attached greenhouse is comparable to simply adding extra southern glazing. If we assume a 1200 BTU per square foot solar gain during the 8-hour daylight period, several hundred square feet of glass can contribute significantly to the heat balance of the house. Furthermore, if in non-collection hours the double glazing can be transformed from an R-value 2 wall to an R-value 8 wall, then the thermal advantage is increased tremendously.

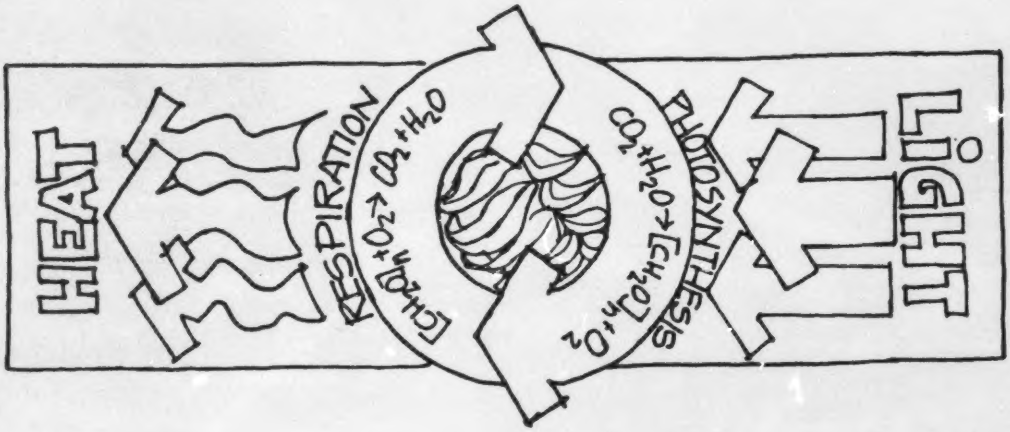
THREE BASIC TYPES

There are three basic types of attached solar greenhouses: 1) direct feed, 2) water wall, and 3) indirect storage. It is the use and placement of thermal mass which differentiates these three types.


DIRECT FEED • WATER WALL • INDIRECT WATER
SUN HEATS WATER DIRECTLY
WARM AIR CIRCULATES TO HEAT WATER

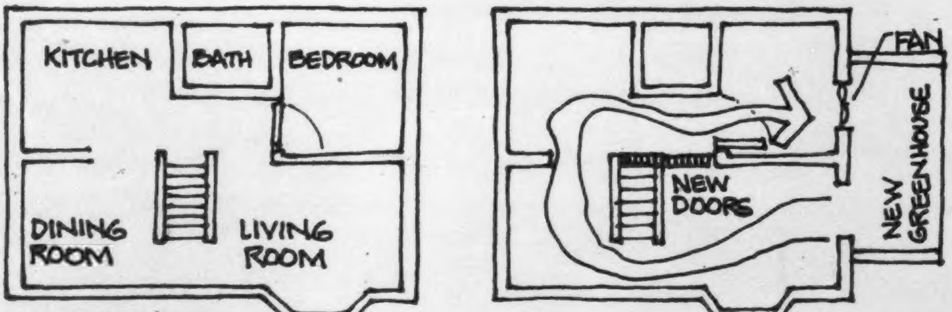
Direct Feed

All oxygen-dependent organisms owe their existence to the good work of plants. The symbiotic exchange between plants which consume CO_2 and give off oxygen and animals which do the opposite is a prerequisite for life as we know it here on earth.


HEAT
RESPIRATION
$[CH_2O]_n+O_2 \rightarrow CO_2+H_2O$
PHOTOSYNTHESIS
$CO_2+H_2O \rightarrow [CH_2O]_n+O_2$
LIGHT

A "direct feed" attached solar greenhouse uses this beneficial exchange between the oxygen-rich greenhouse and the CO_2-ladened house. In a direct feed system, the air in the greenhouse is exchanged directly with the air in the house. In addition to altering the oxygen balance, this air movement can freshen room air and improve humidity levels within the house. The direct feed system relies on the thermal mass and heat losses of the house to absorb excess heat during peak solar gain hours.

In designing a direct feed solar greenhouse, it is important to involve as much of the house's air volume as possible. It is sometimes necessary to add an inside door or wall partition to induce the proper air flows. The use of fans to circulate the air is usually required.


KITCHEN
BATH
BEDROOM
DINING ROOM
LIVING ROOM
FAN
NEW DOORS
NEW GREENHOUSE

DAVIS HOUSE — ENERGY IMPROVEMENTS

Another more passive method of creating this proper air exchange is through the use of natural thermosyphoning. By ducting the warm air that rises to the top of the greenhouse into the second floor of a house, it is possible to induce a natural thermosyphon. The existing warm air is replaced by cool air from the basement or first floor. The rate at which warm air flows is determined by two variables: the height difference between incoming and exiting air and the difference in temperature (ΔT). Sufficient vent areas are required to insure that the proper exchange rate occurs. (See Rules of Thumb section at the end of this chapter.)

Water Wall

A second popular type of attached solar greenhouse uses a water wall system. Because water has the highest heat capacity of any substance, it makes for excellent thermal mass storage.

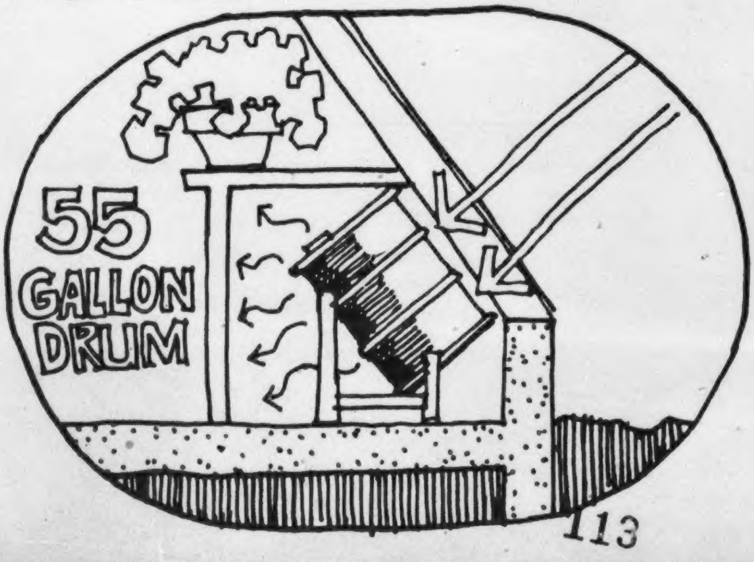
The major design problem has been finding suitable water storage containers. Fifty-five gallon drums, 1-gallon plastic milk jugs, and honey tins have been used most frequently. Ideally, water thermal mass containers should be:

1. non-corrosive when in contact with water
2. easy to fill and place within the greenhouse
3. of high surface area-to-volume ratio
4. dark in color to absorb sunlight

5. made of a material with good heat transmission qualities
6. structurally rigid and stackable

The containers used in the Region #10 Vocational School greenhouse (Navy surplus sono-buoy cases) meet these criteria completely. In addition, the containers are one-third the cost per gallon of milk jugs and will not degrade because of ultraviolet radiation. When filled with water, sono-buoy cases weigh about 45 pounds, a weight that is managable when placing them within the greenhouse.

In designing a water wall system, it is necessary for the water containers to receive direct sunlight. Thermal mass directly exposed is three times more effective than that which is placed out of the sun. In addition, important consideration must be given to the light needs of the plants. If the rear wall of a greenhouse is made up of dark-colored water containers, then there will be less light available for the plants. Placing the dark water wall in view of the sun under the front benches solves the light problem.



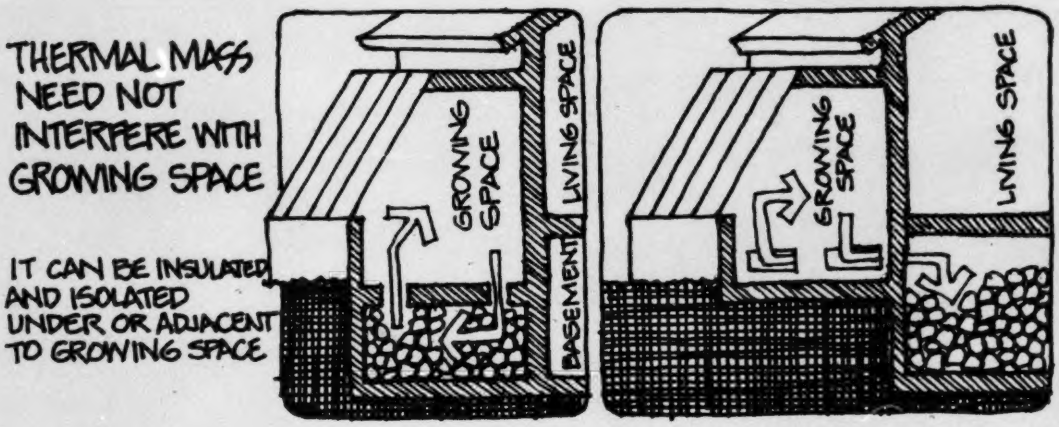
If the water containers are painted dark red or blue they will absorb almost as much heat as if they were black. Beneficial red or blue light is then reflected onto the plants. The interactions between the light and heat needs of plants are extremely complex. The primary end function of the greenhouse (is it a sunspace? a plant production space? a solar collector?) determines the answers to many interior design questions.

The amount of thermal mass will determine the fluctuation in greenhouse temperatures. Ten gallons of water per square foot of glazing will produce a 10F.° fluctuation in a properly designed solar greenhouse. Five gallons of water per square foot of glazing will produce a 20F.° fluctuation in inside temperature. This rough rule of thumb demonstrates that the greater the thermal mass, the less the temperature fluctuation.

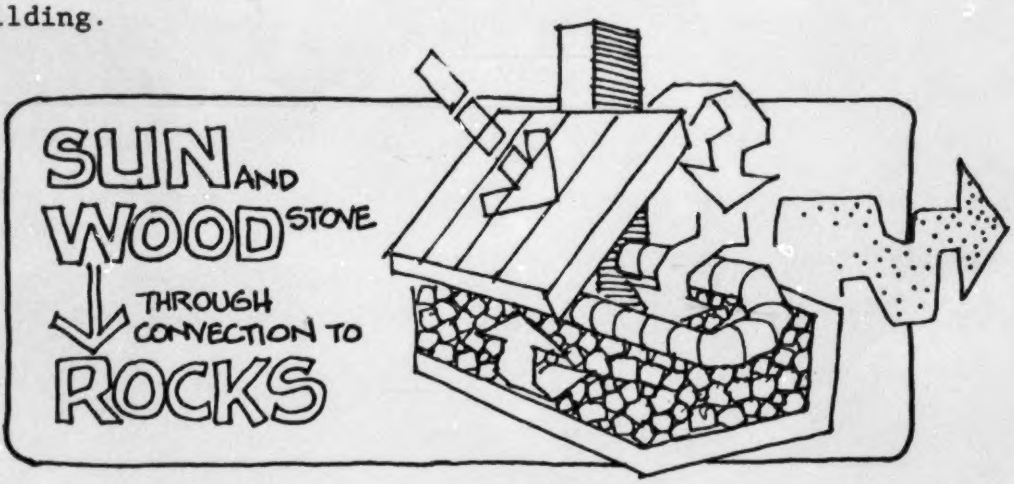
Space occupied by thermal mass inside the greenhouse competes with plant growing space. Therefore great attention must be paid to its placement and effectiveness. The types of crops grown, with their particular light and heat needs, will largely dictate the amount and placement of thermal mass. Cold weather vegetables and even orchids have been developed which can adapt to large temperature swings (30F.°) Other plants require more limited temperature extremes. End use dictates design.

Indirect Storage

The most elaborate and expensive type of solar greenhouse uses indirect storage. In this case the thermal mass (either water or masonry) is placed in a compartment isolated from the interior space. Warm air must be blown from the top of the greenhouse to the storage area. Because the storage area may be in an adjoining room or in an "out of the way" space, it need not interfere with valuable plant growing space.


THERMAL MASS NEED NOT INTERFERE WITH GROWING SPACE
IT CAN BE INSULATED AND ISOLATED UNDER OR ADJACENT TO GROWING SPACE
GROWING SPACE
LIVING SPACE
BASEMENT
GROWING SPACE
LIVING SPACE

The use of an isolated and insulated thermal mass storage area allows for much greater control over inside temperature swings. When the greenhouse needs excess heat, it can be removed from storage. When the greenhouse is sufficiently heated, extra heat from storage can be blown into the adjoining structure. This is similar to the heat retrieval method used in the Maine Audubon Society's active solar building.



In choosing among the three types of greenhouses, many variables enter into the decision: cost, aesthetics, and end use. The following rules of thumb are not meant to be definitive rules, but rather general guidelines for attached solar greenhouse design.

RULES OF THUMB (For Maine, 44°N. Latitude)

1. The greenhouse should face within 30° east or west of true south.
2. The southern glazing can be tilted between 45°-90° without paying a severe penalty.
3. The greenhouse glazing should receive very little or no shading between 9 a.m. and 3 p.m. during the winter.
4. The south wall should be double glazed with insulating shutters or shades to achieve an R-value greater than 5.0.

5. The foundation should be insulated down to the frost depth with 2" of styrofoam or the equivalent.
6. The greenhouse surfaces should be as air-tight as possible.
7. For direct feed you must be able to exchange 10 cubic feet of air per minute with the house for each square foot of glazing.
8. For water walls, you need at least five gallons per square foot of glazing.
9. For indirect storage, you need two cubic feet of 1-3" stone per square foot of glazing.

CHAPTER ELEVEN

ACTIVE SOLAR

About one-quarter of the total energy produced in the United States each year is used to heat interior living space and water for domestic purposes. Because neither of these applications requires extremely high temperatures, solar energy collection can be matched with high efficiency to these tasks.

When the phrase "solar energy" is mentioned, most people think of flat plate collectors mounted on the roof. However, active solar space heating is just one of many solar applications commercially available today. The major advantage of active collectors over passive solar systems is that they can be "tacked on" to almost any existing structure which is exposed to the sun. However, the economics of large scale active solar application are sometimes questionable.

The distinctions among active, hybrid and passive systems (see glossary in Chapter 1) depend on the relationship between energy delivered and non-renewable energy inputs. Generally speaking, active solar systems rely on the use of pumps and blowers to circulate a transfer fluid which extracts useful heat. The major principle of active solar collection is simple: you take a hot black roof, put a cover on it, circulate a fluid through this space, and extract the resultant heat. Active systems are generally classified as being one of two types: air or liquid. Either system has the following basic components: collectors, storage, distribution equipment, controls, and auxiliary heat.

The efficiencies of commercial quality solar systems range between about 50% and 70%. These percentages represent the amount of solar energy striking the solar collector that is delivered to the living space as useful heat. An efficient flat plate collector in Maine can capture about 120,000 BTU per square foot per season. If the annual heating load of an average house is around 150,000,000 BTU, then a collector array of about 1200 square feet could supply the annual load. However, the cost effectiveness of 100% solar heating is dubious.

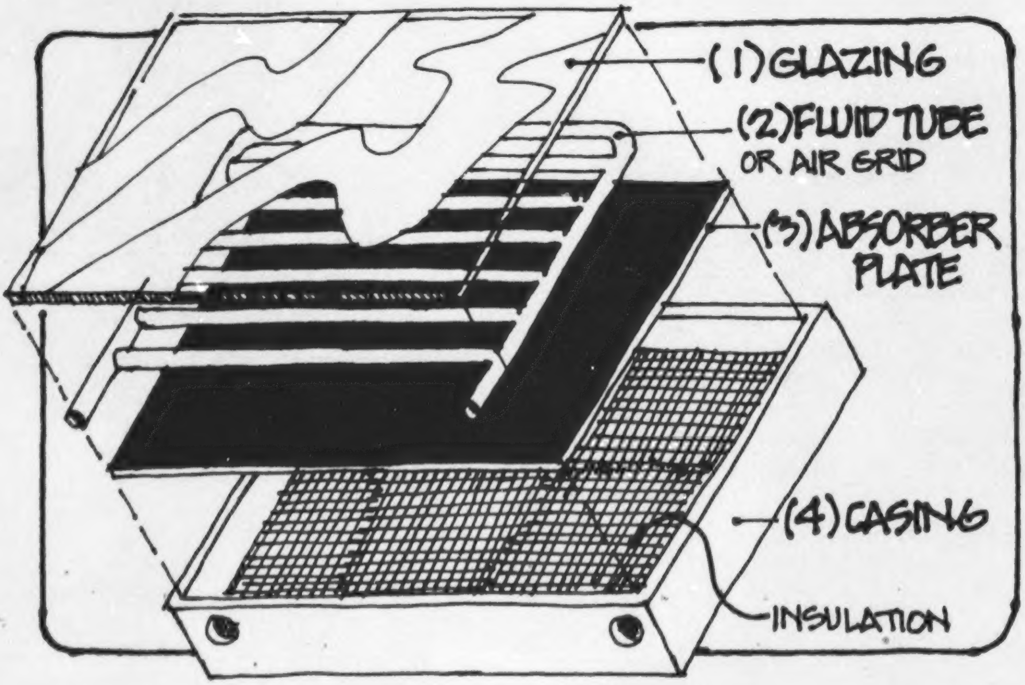
It is wise to consider active solar heating as a tempering strategy rather than as a sole source. The cost of supplying the maximum daily load with solar may not be justifiable. In other words an active system should be designed to supply a substantial portion of a building's heating load but not all of it. For example, the Maine Audubon building's active solar system provides about two-thirds of the building's annual needs. A wood furnace supplies the remaining one-third.

Maximizing the cost benefit of an active solar system depends on a variety of factors which include fuel prices, initial investment, inflation, and maintenance costs. Finding the optimum ratio of solar to back-up heat is a major design problem. All economic analyses become meaningless if today's conventional fuels become unavailable. The economics of active solar systems could become positive overnight if our region's oil supply were cut off. These possibilities are not thought of by most Americans whose lifestyles assume an unlimited supply of resources.

Even the concept of life cycle costing is not considered important by most Americans. Active solar systems can be determined cost-effective if viewed from a life cycle costing perspective. This tool of economic analysis looks at all the costs of a system (i.e. initial investment, fuel, financing, and maintenance costs) and compares them to the savings of the system during its useful life. Many active solar systems can "pay for themselves" (i.e. return in savings to the owner amounts greater than their total cost) in less than 20 years. Yet most Americans don't look at the total system cost; they consider only the first cost. It is for this reason that electric heat is often chosen over other forms -- because of its low first cost. In reality, the savings built up because of this lower first cost are quickly erased by high fuel costs. Electric heat is often a poor choice.

A FLAT PLATE COLLECTOR

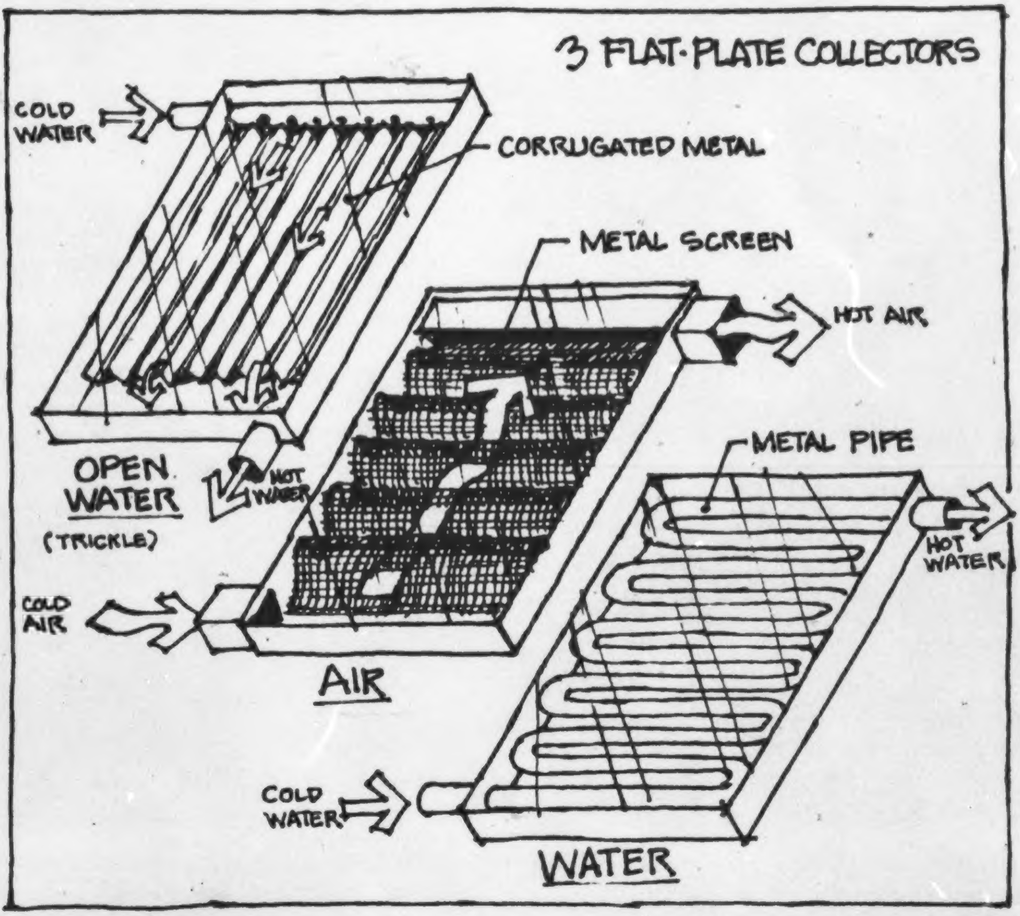
The heart of most active solar systems is the flat plate collector. Its three major components are the cover, the absorber, and the insulated casing which contains the whole device. The performance of any collector is largely a function of the amount of incident radiation, the absorptiority and emissivity (relative powers of a surface to absorb and re-emit radiation) of the surface of the collector plate, the amount and type of insulation of the collector, and the optical characteristics of the cover sheet. Detailed technical information on the specifics of each component part is readily available.



The general functions of the component parts are as follows: 1) the glazing consists of a material (usually glass or plastic) which allows a large amount of light to pass through, but at the same time prevents the long wave (or heat) radiation from escaping. A double glazing provides an air space to act as the thermal barrier. 2) A fluid or air duct grid mounted below the glazing captures and transports the heat either to the living space or to the storage area. 3) An absorptive plate, generally black in color, absorbs the radiation and conducts or convects it to the transport fluid (water or air). 4) A casing which shields and insulates the components from the outside weather. This casing must be designed to attach easily to mounting brackets, which are in turn secured to the structure or the ground.

FLAT PLATE COLLECTOR TYPES

There are three common flat plate collector types: 1) closed-loop water, 2) water trickle, and 3) air.


3 FLAT-PLATE COLLECTORS
COLD WATER
CORRUGATED METAL
METAL SCREEN
HOT AIR
OPEN WATER
(TRICKLE)
HOT WATER
METAL PIPE
HOT WATER
COLD AIR
AIR
COLD WATER
WATER

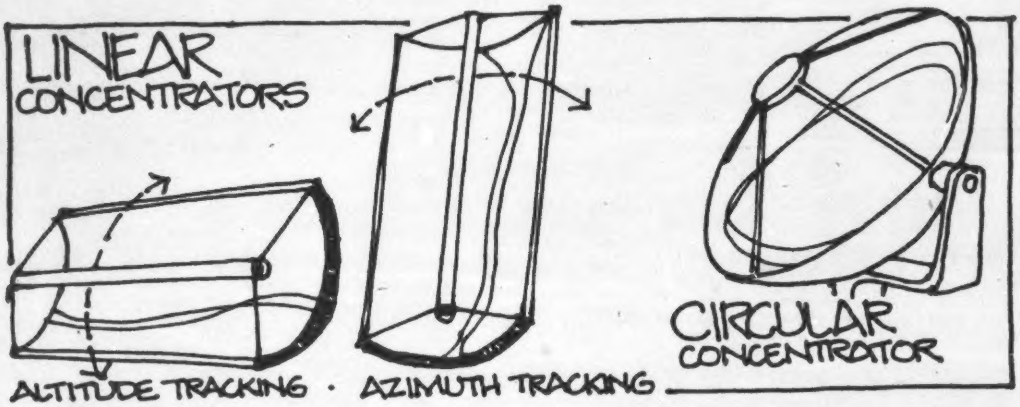
Liquid collectors are the most common type of collector now available. Water or a water/anti-freeze solution is used as the heat transfer medium. The fluid is piped under pressure or by thermosyphon through tubing that is either attached to or integral with the absorber plate. The fluid is collected at the other end of the absorber plate and piped to the storage area.

The water trickle system (such as the one on the Davis house in Bar Harbor, Maine) consists of black corrugated metal roofing panels with a system of water flowing from top to bottom. The water is fed from a supply pipe at the top of the system, trickles down the troughs of the absorptive panel where it is heated and is then collected in a gutter at the bottom where it is transported to storage.

Air systems rely on passing relatively large volumes of air (about 2 cubic feet per minute per square foot of glazing) over absorber plates. The Maine Audubon active air system uses ordinary insect screening stapled onto black-painted plywood. Because air has a much lower heat capacity than water, a much larger volume of transport fluid is required.

CONCENTRATING COLLECTORS

Concentrating or focusing collectors intensify the sun's energy and then collect it. They consist of curved, mirror-like surfaces, some parabolic in shape, others trough-like. The collector receives and reflects the sun's rays onto a small absorbing surface where the storage medium is heated. Concentrating collectors function at maximum efficiency only when direct radiation is being received. For this reason they are best suited to regions with very clear skies.



Linear concentrating collectors (linear trough-like collectors) are curved in one direction. This type of collector focuses radiation onto a pipe or tube absorber. Fluid is circulated through the tube where it picks up the absorbed heat and transports it to a storage area.

Circular concentrating collectors have a concave, reflective surface, often parabolic in shape, which is used to focus solar radiation on point target areas. The absorber is located at the focal point where it collects heat. The heat is then transported by a fluid to the storage area. The circular concentrating collector must track the sun in order to take advantage of the most direct solar radiation.

SITE-BUILT VS. COMMERCIAL COLLECTORS

There exists a growing school of thought which advocates site-built collectors over those commercially available. The primary advantage of site-built collectors is their greatly reduced cost. Because site-built collectors can be constructed as an integral part of the building envelope, the overall cost of the project can be reduced. In the case of site-built systems, the collector becomes the roof. For example, the price of the Maine Audubon collectors was about $4.50 per sq. ft. installed, as opposed to commercial units which could have cost 3 to 4 times that figure.

A disadvantage of most site-built collectors is that they are not as efficient as commercially available units. This trade-off between efficiency and cost is a key design issue for all active systems. As tax credits for solar installations become a reality, and as a corps of solar installers becomes educated, the costs of active solar will compare more favorably with traditional fuels. Without widespread public support for solar energy tax credits, technical education, and highly visible demonstration projects, the switch to renewable-energy sources will be an agonizing, drawn-out affair.

CHAPTER TWELVE

SOLAR HOT WATER

The idea of heating water with the sun is familiar to almost everyone. The hot water from a garden hose left out on a summer lawn has provided many people with their first experience with solar power. Using the sun's energy to heat water is an age-proven concept which is now being seriously considered as a practical solution to one aspect of the current energy crisis.

In Los Angeles, California, one company had installed more than 1600 solar hot water heaters by 1900. The same basic principles used in these systems apply today. People in harsher climates like Maine can take advantage of breakthroughs in materials (for instance, plastic films and selective surfaces for metal sheets) and products (differential control thermostats and anti-freeze solutions) which make solar hot water heating feasible. Because of our cold ground water temperatures, solar assisted hot water systems are economically justified at current electric prices. (Rarely are temperatures achieved high enough to make solar-assisted baseboard space heating feasible. The amount of energy available in the first place, the required temperatures, and the heat losses at each exchange make direct baseboard heating impractical.)

With the 30% tax credit from the National Energy Act and lower installation costs that come from increased experience of the technicians, solar hot water is beginning to prove itself in Maine. The state Office of Energy Resources reports widespread approval and acceptance of solar hot water systems by the consumers who participated in a pilot project funded by the state.

A recent newspaper article stated, "The experience of the grantees seems to suggest that solar hot water heating is considerably more practical than sometimes thought." With favorable tax incentives, and a $400 grant from the state for each installation, the systems will pay back in 5 to 7 years. Widespread commercialization of flat plate collectors and an experienced corps of competent installers could result in a cost reduction equal to the $400 grants from the state. Until solar receives the same order of financial subsidy given to the oil and nuclear industries, however, solar will be at a competitive disadvantage.

HOT WATER AND ENERGY USE

In terms of the overall energy picture, hot water seems like a small portion of our state's demand. However, it is in this specific area that any family can take direct action to curb its energy use. About 20% of the energy in a home is used to heat water for domestic purposes. On a national scale, about 4% of our country's total energy consumption is devoted to heating hot water.

Domestic hot water generally does not have to be hotter than 120°F. Water in excess of 110°F. is uncomfortable to the touch. Because solar hot water systems are capable of providing hot water at up to 200°F. in the summer and higher than 100°F. in the winter, solar hot water systems are an excellent match between a low grade source of heat (the sun) and a common household task: heating hot water. During cold winter months a solar system will be able to supply probably no more than 50% of a family's hot water needs. However, by using the solar system, the conventional heating system is able to use just that much less non-renewable energy. The principle of solar tempering is once again at work.

HOT WATER CONSERVATION

The average family uses about 20 gallons of hot water per person per day. At this rate a family of four uses about 2500 gallons of hot water per month, and 30,000 gallons per year. If we assume the average year-round ground water temperature in Maine to be 45°F., and the average hot water temperature to be 140°F., then we can compute the annual energy cost:

-- 30,000 gal/yr x 8.3 lbs/gal x $(140^{\circ}-45^{\circ})$F. = 23,655,000 BTU/yr

-- if electricity costs 4¢/kWh, and 3,410 BTU = 1 kWh, then the cost for this hot water per year equals:

-- 23,655,000 BTU/yr x 1 kWh/3,410 BTU x \$.04/kWh = \$277. or about \$23. per month

In order to make the most of the cost effectiveness of a solar hot water system, certain conservation measures should be taken first. For example: lower the hot water thermostat to 120°F., insulate the hot water tank and hot water pipes with fiberglass batts, install energy-conserving shower heads, wash clothes in cold or cool water, take shorter showers. It has been estimated that with careful planning the average family could cut its hot water use in half. Energy conservation (through hot water conservation) once again goes hand in hand with solar heating.

SOLAR HOT WATER THEORY

The most important design concept to understand is that a solar system attempts to remove thermal energy from the collector and deliver it to storage as efficiently as possible. To do this, the transfer fluid should be delivered to the collector at the lowest possible temperature. A flat plate collector should not try to maximize temperatures but rather capture and give off to the transfer fluid the maximum number of BTU. Lots of heat, not a high temperature, is what is needed. The outside glazing of a solar collector should not feel warm to the touch. If it does, it is losing valuable heat to the atmosphere.

COMMERCIAL SYSTEMS

There are three basic types of commercially available solar hot water units: 1) pumped, closed-loop anti-freeze, 2) drain down, and 3) phase change (Freon). The most common system in use today is the closed-loop anti-freeze. These systems require protection against below-freezing temperatures. Glycols, mineral oils, and silicone oils have been used. The following comparisons can be made:

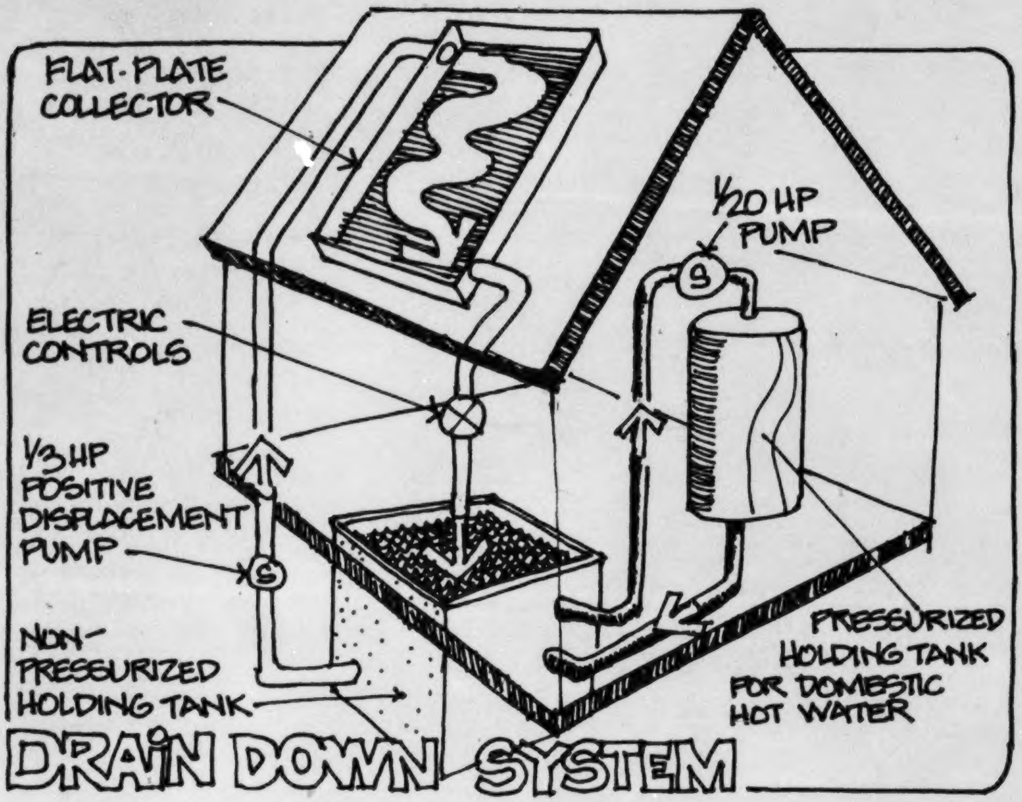
Substance	Specific Heat	Cost/Gallon	(+) Advantages (-) Disadvantages
water	1.0	free	+ inexpensive + drinkable - freezes - corrosive
propolyne glycol	.53	$7.50/gal	+ commonly available
ethelyne glycol	.55	$7.50/gal	- toxic in large quantities
mineral oil	.50	$6.50/gal	+ won't degrade + non-toxic - corrosive to leather and certain types of rubber
silicone oil	.33	$35/gal	+ stable + non-toxic - expensive - requires greater pumping power because of viscosity

These commercial closed-loop anti-freeze systems require a flow of about 3 gallons per minute for most efficient heat exchange. Most systems are supplied with expansion tanks, pumps (1/20-1/25 horsepower), tempering valves, heat exchangers, electronic controls, and a variety of conventional plumbing fixtures. A number of detailed books and complete technical courses are offered to teach specific installation and maintenance skills.

A drain-down system differs from a closed-loop anti-freeze system in that water is used as the medium of heat exchange. The advantages of using water directly are that: 1) water has a high heat capacity and therefore acts as a good heat transfer fluid, and 2) high heat transfer occurs because no heat exchanger is required -- the water is heated directly.

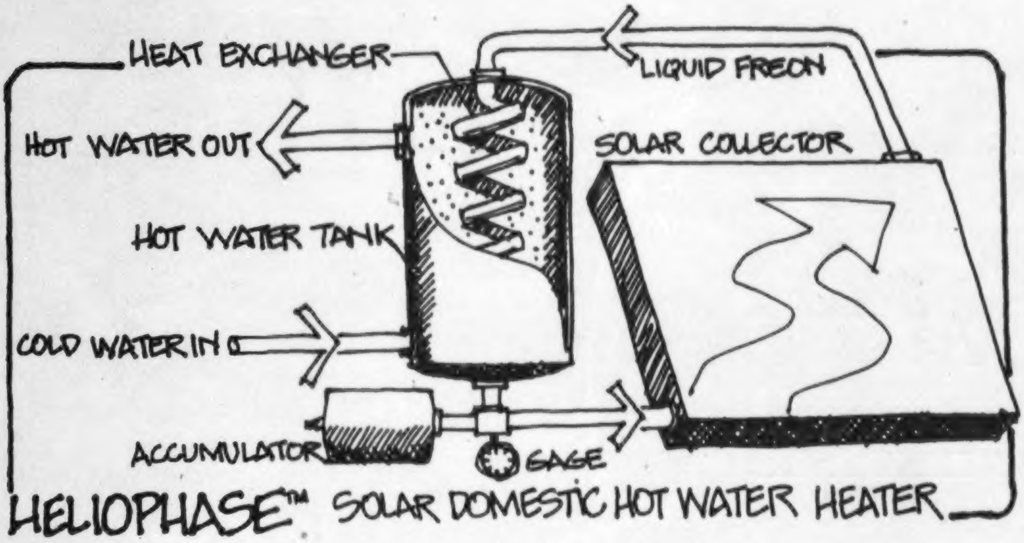
The two major disadvantages are: 1) the system is extremely vulnerable to freezing if a solenoid valve sticks or if thermal sensors fail, and 2) a large positive displacement pump (1/3 horsepower) must be used to overcome the weight of the water in the vertical pipes. A typical drain-down system is set up as shown on the following page.

In a drain-down system the pipes must be pitched correctly to let gravity do its work. Furthermore, air must be allowed back into the system so that complete draining takes place.


FLAT-PLATE COLLECTOR
1/20 HP PUMP
ELECTRIC CONTROLS
1/3 HP POSITIVE DISPLACEMENT PUMP
NON-PRESSURIZED HOLDING TANK
PRESSURIZED HOLDING TANK FOR DOMESTIC HOT WATER
DRAIN DOWN SYSTEM

It is essential that mineral deposits from "hard water" not be allowed to build up and interfere with the heat exchange between the collector and the water.

The third basic type of solar hot water collector uses a Freon® 114 refrigerant as the heat transfer fluid. The system relies on the Freon vapors condensing at a particular temperature. Materials which undergo phase change (changing from liquid to solid to gas and vice versa) liberate and absorb tremendous amounts of heat. This phase-change system uses no pumps. It does require standard refrigerant installation techniques. The accumulator is set for a particular vapor pressure. Once charged, the system runs by itself.


HEAT EXCHANGER
LIQUID FREON
HOT WATER OUT
SOLAR COLLECTOR
HOT WATER TANK
COLD WATER IN
ACCUMULATOR
GAGE
HELIOPHASE™ SOLAR DOMESTIC HOT WATER HEATER

SELECTIVE SURFACES

All of these commercially available systems use relatively high technology collectors. One particular feature of commercial panels is the use of selective surfaces on the absorber plates of the collectors. The purpose of a selective surface is to trap as much solar energy as possible. This effect is created by choosing materials having high absorptivities (the ability to absorb radiation) and low emissivities (the ability to radiate infrared energy). In other words, a selective surface coating is very efficient at trapping and holding solar radiation.

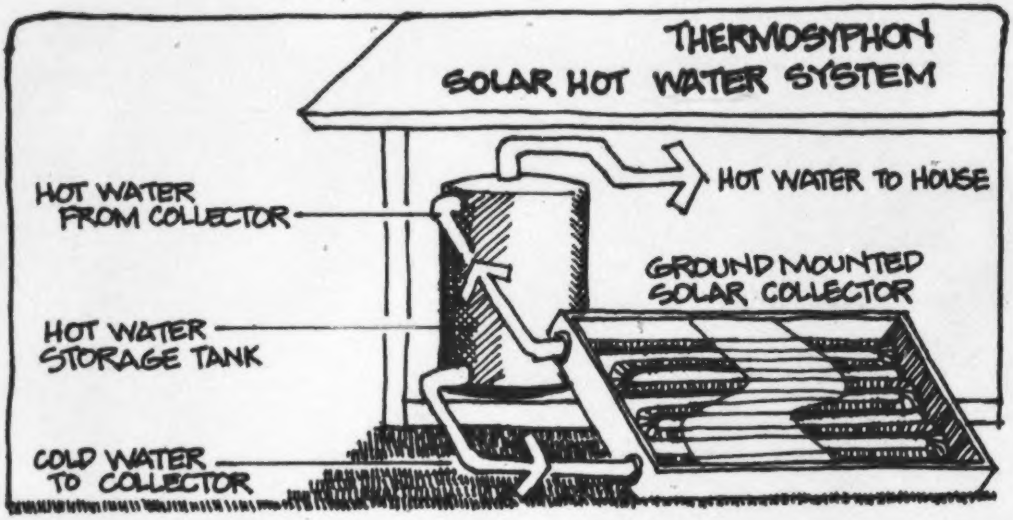
Flat black paint has an absorptivity of about 0.85, i.e. it absorbs about 85% of the maximum possible. However, this surface has an equally high emissivity rate. Black chrome on copper, like that used in the Sun Works collector, has an absorptivity of about 0.95, but an emissivity of only 0.10. The major problem is that this particular surface is very difficult for the homeowner to apply. It is also very expensive.

SITE-BUILT COLLECTORS

Site-built collectors offer a reasonable alternative to expensive commercial units. A relatively efficient collector can be built for around $200, excluding cost of labor. Northeast Carry, in Hallowell, Maine, has conducted workshops on constructing flat plate collectors. They estimate that a complete thermosyphon hot water system can be built for around $700.

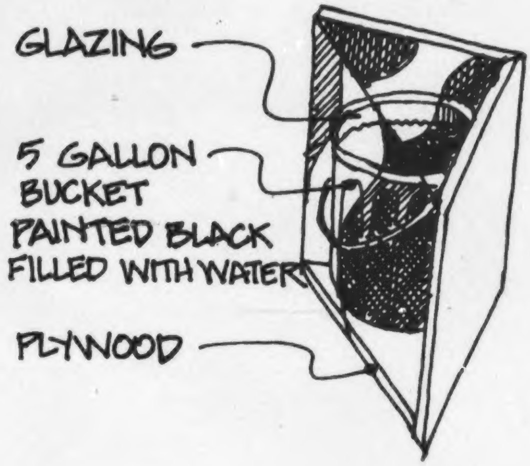
It is clear that site-built collectors offer the greatest opportunity for tradespeople. Collectors that are an integral part of the building structure serve a dual purpose. Also, the use of recycled materials can greatly reduce system costs. Both thermosyphon and bread box hot water heaters may once again see widespread acceptance in summer cottages and camps.

The thermosyphon system relies on the natural circulation of warmer (more buoyant) water. It is necessary for the top of the collector to be at least two feet below the storage tank. Like air re-circulation in a Trombe wall, it is necessary to prevent reverse thermosyphoning. In this hot water system an anti-syphon valve is used to prevent reverse flow.

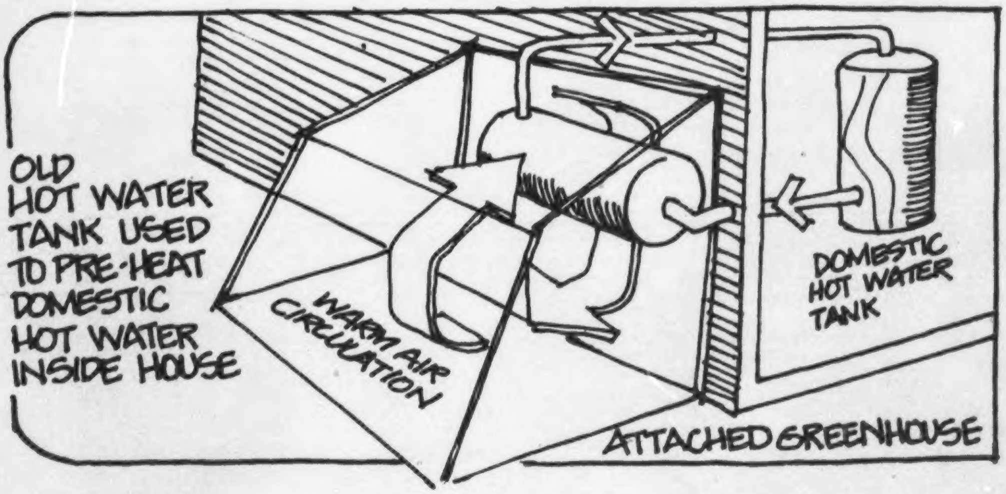

THERMOSYPHON
SOLAR HOT WATER SYSTEM
HOT WATER TO HOUSE
HOT WATER FROM COLLECTOR
GROUND MOUNTED SOLAR COLLECTOR
HOT WATER STORAGE TANK
COLD WATER TO COLLECTOR

Bread box heaters are merely insulated boxes with appropriate glazing and reflectors to maximize solar energy capture.

A dark painted 5-gallon bucket in a triangular paper or plywood box can supply a limited amount of hot water.


GLAZING
5 GALLON BUCKET PAINTED BLACK FILLED WITH WATER
PLYWOOD

Another innovative suggestion calls for the placing of recycled steel hot water tanks in the top of an attached solar greenhouse. With air temperatures as high as 90°F. at the top of the greenhouse, the units can serve as an effective preheater for conventional domestic units. In this case solar energy is used to temper the heating load.


OLD HOT WATER TANK USED TO PRE-HEAT DOMESTIC HOT WATER INSIDE HOUSE
WARM AIR CIRCULATION
DOMESTIC HOT WATER TANK
ATTACHED GREENHOUSE